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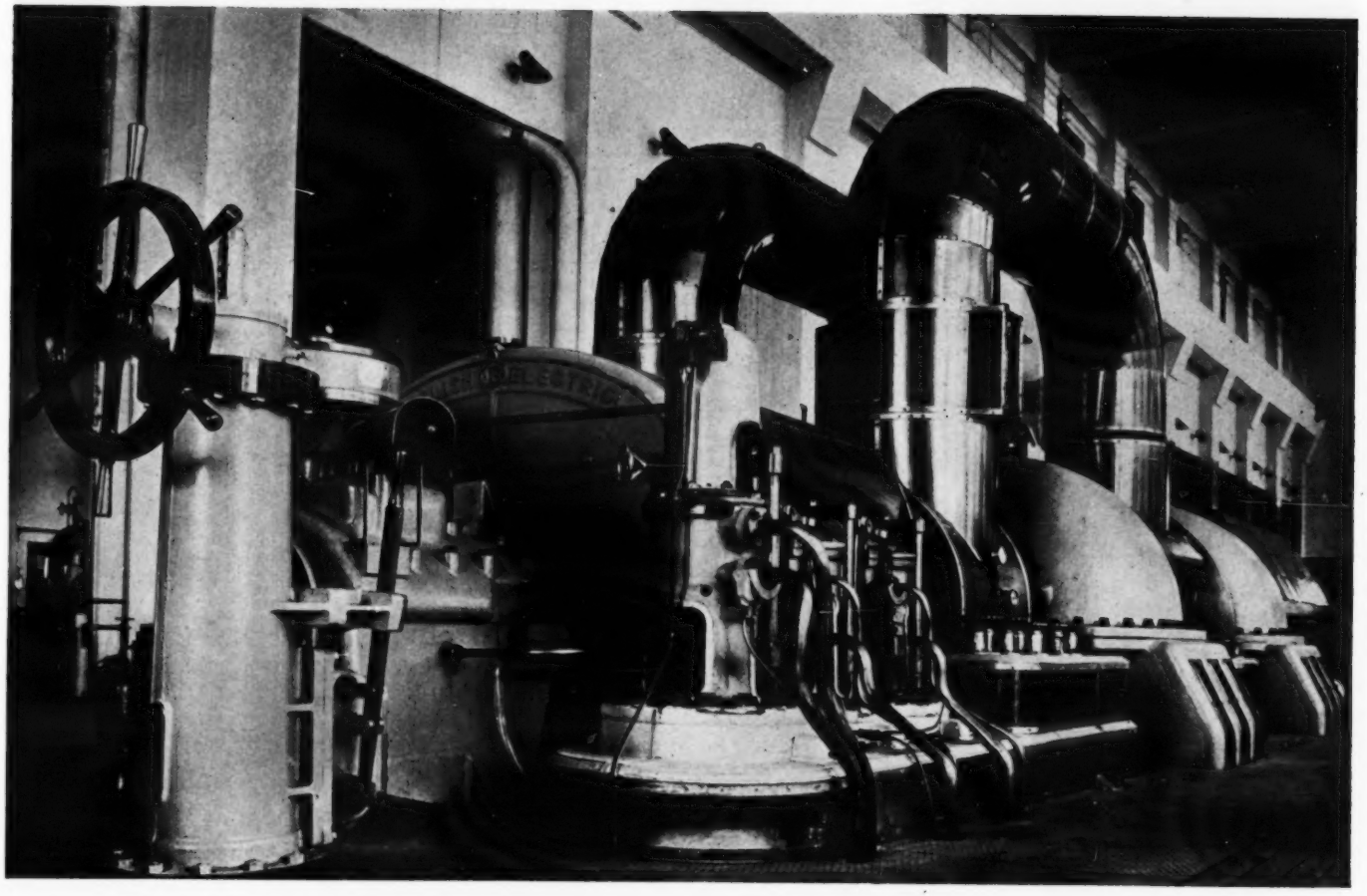


The 30,000 kW 'English Electric' steam turbo-alternator set in the Salmisaari Power Station of the City of Helsinki, Finland

Heat Consumption of Modern Steam Power Plant

By HARALD FRILUND

This article is a translation of the first part of a paper by Professor Harald Frilund, Member of IVA, Stockholm, and Managing Director of the Finnish Power and Fuel Economy Association, EKONO. It is published in this Journal by the courtesy of the author.

IN JUNE, 1953, EKONO carried out tests on the new steam power plant of the City of Helsinki at Salmisaari. The results are given in this article and a comparison is made between this plant and the City's old plant in Suvilahti. A comparison is also made with a large high-pressure power plant in Germany. Finally, the reasons for the decrease in heat consumption are analyzed.

I. THE SALMISAARI STEAM POWER STATION OF THE CITY OF HELSINKI

JUNE 1953

Turbine : 30 MW, ' English Electric,' two-cylinder.

Initial steam pressure $p_1 = 56$ atm abs (782 p.s.i.g.)

Initial steam temperature $t_1 = 485°C$ (905°F)

Cooling water temperature $t_k = 10°C$ (50°F)

3-stage feed heating to 146°C (295°F) at 30 MW (see Table I).

Boiler : Babcock & Wilcox C.T.M. type with chain grate, 110 metric tons/h (243,000 klb/h).

Heat Consumption (0—24 MW)
(1kcal = 3·97 B.Th.U.)

Referring to the graph in Fig. 1 :—

1. Turbine, including auxiliaries—

$$\frac{202}{k} + 2129 \text{ kcal/kWh}$$

2. Turbine and boiler, including auxiliaries, continuous running—

$$\frac{283}{k} + 2304 \text{ kcal/kWh}$$

3. Turbine and boiler, including auxiliaries and standing losses—

$$\frac{333}{k} + 2260 \text{ kcal/kWh}$$

k = output factor. k = 1 corresponds to 30 MW.

No-load Consumptions

Turbine :

Turbine alone—$5{\cdot}45 \times 10^6$ kcal/30,000 kW = 182 kcal/kW = 7·0%

Auxiliaries—$0{\cdot}61 \times 10^6$ kcal/30,000 kW = 20 kcal/kW = 0·8%

Turbine total—$6{\cdot}06 \times 10^6$ kcal = 202 kcal/kW = 7·8%

Boiler :

Boiler alone—$1{\cdot}38 \times 10^6$ kcal/30,000 kW = 46 kcal/kW = 1·8%

Auxiliaries—$1{\cdot}06 \times 10^6$ kcal/30,000 kW = 35 kcal/kW = 1·3%

Total—$2{\cdot}44 \times 10^6$ kcal = 81 kcal/kW = 3·1%

Standing losses—$1{\cdot}50 \times 10^6$ kcal = 50 kcal/kW = 1·9%

Boiler total—$3{\cdot}94 \times 10^6$ kcal = 131 kcal/kW = 5·0%

Totals :

Grand total (boiler + turbine) — $10{\cdot}00 \times 10^6$ kcal/30,000 kW = 333 kcal/kW = 12·8%

Total no-load loss = 333/(333 + 2260) = 333/2593 = 12·8% say 13%

Total Heat Consumption

$$\frac{333}{k} + 2260 \text{ kcal/kWh}$$

Load	%	20	40	60	80	(100)	
,, ...	MW	6	12	18	24	(30)	28 MW max.
No-load consumption ..	kcal/kWh	1670	835	555	415	(333)	
Nett consumption ..	,,	2260	2260	2260	2260	(2260)	
Total consumption ..	,,	3930	3095	2815	2675	(2593)	2780
Coal (6,000 kcal/kg) ..	kg/kWh	0·655	0·515	0·469	0·446		0·463
,, (13,200 B.Th.U/lb)	lb/kWh	1·44	1·14	1·03	0·985		1·02
Thermal efficiency ..	%	21·9	27·8	30·6	32·2		31·0

Nett efficiency = 860/2260 = 38%.

TABLE I

Heat consumption tests on 30 MW 'English Electric' condensing turbine, in June 1953.

Normal conditions:

Initial steam pressure	56 atm abs (782 p.s.i.g.)
Steam temperature	485°C (905°F)
Circulating water temperature	10°C (50°F)
Circulating water quantity	4,500 m³/h (16,500 g.p.m.)
Speed	3,000 r.p.m.
Alternator voltage	5,500 V
Power factor	$\cos \varphi = 0{\cdot}8$

Three un-regulated bled steam points for feed heating to 146 C (295°F) at 30 MW load.

Three automatic throttle valves for partial load regulation.

The turbine is a two-cylinder machine with double-flow L.P. casing and twin shell condensers.

Test	No.	1	2	3	4	5
Duration	sec	5312	3800	3897	4407	3882
Atmospheric pressure	mm Hg	758	758·5	761	761	761
,, ,, ...	in. Hg	29·85	29·87	29·97	29·97	29·97
Steam Pressure:						
Before the turbine	atm abs	60·4	58·6	60·2	57·7	56·2
,, feed heater No. I	,,	0·090	0·139	0·208	0·257	0·323
,, ,, ,, ,, II	,,	0·386	0·613	0·943	1·142	1·376
,, ,, ,, ,, III	,,	1·26	2·26	3·27	4·22	5·59
In the exhaust, average (by temperature measurement)	,,	0·0213	0·0261	0·0317	0·0374	0·0463
Equivalent vacuum (Bar. 30 in) ..	in. Hg	29·38	29·24	29·08	29·91	28·65
Steam Temperature:						
Before the turbine	C	475	489	490	487	492
,, feed heater No. I	,,	58·3	65·5	60·3	65·1	70·2
,, ,, ,, ,, II	,,	73·5	86·0	96·4	102·6	109·3
,, ,, ,, ,, III	,,	166	197	208	220	251
In the exhaust	,,	18·2	21·5	24·7	27·5	31·2
Condensate temperature:						
After the condenser	C	18·9	21·6	24·5	26·4	29·5
Before the drain cooler	,,	25·9	26·1	28·2	29·0	32·1
After ,, ,, ,, ...	,,	29·6	32·6	35·6	36·9	39·5

(Continued)

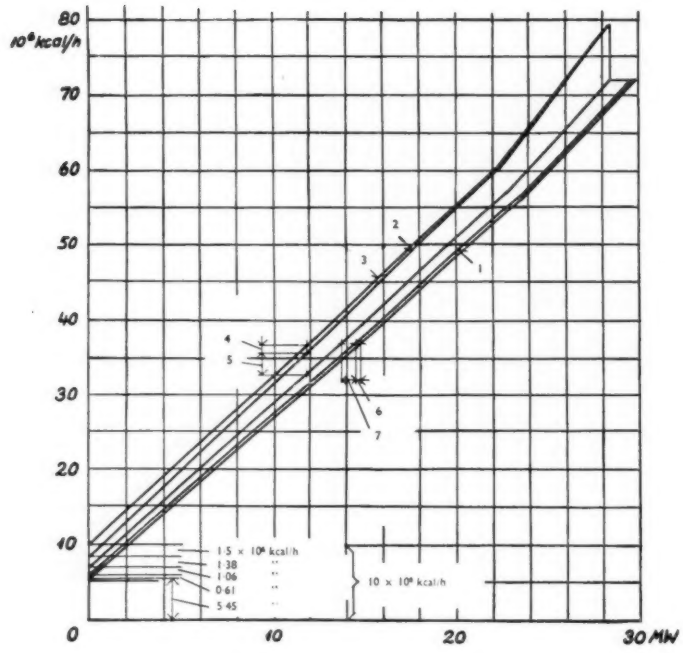
TABLE I (*Continued*)

Test	No.	1	2	3	4	5
Before feed heater No. I	°C	29·4	32·3	35·4	36·4	38·9
After „ „ „ I	„	42·6	50·4	58·4	62·0	66·2
Before „ „ „ II*	„	45·3	51·5	59·7	62·8	66·9
„ „ „ III	„	73·0	85·1	95·0	100·2	106·7
After „ „ „ III	„	105·1	122·3	134·0	142·5	152·0
Temperature of heater drains:						
Before the drain cooler	C	34·1	45·0	62·2	65·6	70·2
After „ „ „	„	30·5	34·7	38·2	40·4	42·5
Circulating water:						
Temperature, inlet	C	14·0	14·1	14·7	15·2	15·8
„ outlet	„	16·7	18·5	20·8	22·3	24·7
Quantity (calculated)	m³/h	4620	4620	4670	5040	5230
„ „	g.p.m.	16950	16950	17100	18500	19200
Alternator:						
Output	kW	5919	11925	18186	23636	29827
Fan power	„	70	70	70	70	123
Nett output (excluding condenser auxiliaries)	„	5849	11855	18116	23676	29704
Condenser auxiliaries	„		not measured		238	243
Voltage	V	4962	5285	5393	5413	5489
Current	A	881	1691	2489	3350	3952
Power factor	cos φ	0·783	0·773	0·783	0·759	0·794
Steam consumption	kg/h	26130	44490	66380	85540	110600
Heat consumption:						
Per hour	Mcal/h	18190	31270	44845	56970	72940
Specific consumption	kcal/kWh	3110	2638	2475	2406	2456
„ „	B.Th.U/kWh	12340	10468	9821	9547	9745
Heat consumption reduced to normal conditions:						
Output (excluding condenser auxiliaries)	MW	6	12	18	24	30
Heat consumption per hour	Mcal/h	18235	31175	43885	56545	72150
Specific consumption	kcal/kWh	3039	2598	2438	2356	2405
„ „	B.Th.U/kWh	12059	10309	9674	9348	9543

* *The feed water pump connected between the first and the second feed heater.*

TABLE II

Plant	Suvilahti	Salmisaari	Germany
Turbine:	Vickers	English Electric	'Musil'
Output .. .. MW	10	30	50
Initial pressure .. .. atm abs	13	56	105
„ „ .. .. p.s.i.g.	170	782	1480
„ temperature C	300	485	485
„ „ .. .. .. F	572	905	905
Circulating water temperature .. C	5	10	*not quoted*
„ „ „ .. F	41	50	*not quoted*
Final feed temperature C	70	146	*not quoted*
„ „ „ .. .. .. F	158	295	*not quoted*
Reheat	no	no	yes



1. Turbine (with Auxiliaries) $\frac{202}{k}$ + 2129 kcal/kWh
2. Turbine + boiler (continuous running) $\frac{283}{k}$ + 2304 kcal/kWh
3. Turbine + boiler + standing losses $\frac{333}{k}$ + 2260 kcal/kWh

k = output factor (k = 1 corresponds to 30 MW)

4. Standing losses
5. Boiler losses
6. Internal consumption of turbine (condenser)
7. Internal consumption of boiler (fans, feed pumps, etc.)

Fig. 1. (*above*)—*Heat Consumptions at Salmisaari* (*June*, 1953) :

Turbine : 30 *MW* ' *English Electric* ' 2-*cylinder*
p_1 = 56 *atm abs* (782 *p.s.i.g.*)
t_1 = 485°*C* (905°*F*)
Circ. water temp. 10°*C* (50°*F*)
3-*stage feed heating to* 146°*C* (295°*F*) *at* 30 *MW.*

Boiler : *B. & W. C.T.M. type with chain grate,* 110 *metric tons/h.*

II. ANALYSIS OF THE FACTORS DETERMINING THE DECREASE IN HEAT CONSUMPTION

A detailed analysis of the heat consumption of the Suvilahti Power Plant of Helsinki Municipality was made in a paper delivered by the author at the annual meeting of Svenska Teknologföreningen in Stockholm on the 18th March, 1932. The following comparative analysis of the heat consumptions of the Suvilahti and Salmisaari plants is now made. As a further comparison the heat consumption figures from a large power plant in Germany have been included (Dr. techn. Ludwig Musil, ' Die Gesamtplanung von Dampfkraftwerken,' 1948, pages 9 and 10).

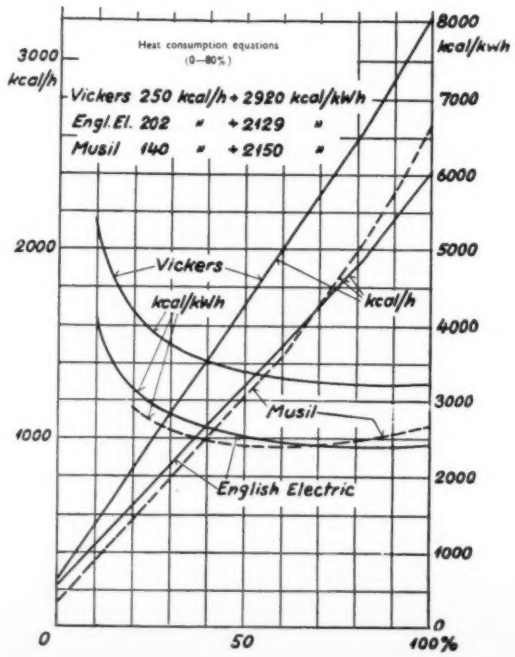


Fig. 2.—*Comparative specific heat consumptions of Vickers* (*Suvilahti*), *English Electric* (*Salmisaari*) *and* ' *Musil* ' *turbines.* (*Vickers and English Electric including auxiliaries,* ' *Musil* ' *excluding auxiliaries*)

Steam Turbine Heat Consumptions

Heat consumptions of the three steam turbines are as shown in Fig. 2, and Table II gives comparative technical data for the three machines.

The heat consumptions shown diagrammatically in Fig. 2 are tabulated below. The figures for the Vickers and English Electric machines include auxiliaries, and those for ' Musil ' exclude auxiliaries :—

Vickers :

250 kcal/h+2920 kcal/kWh (from 0-80% load)

English Electric :

202 kcal/h+2129 kcal/kWh (from 0-80% load)

' Musil ' :

140 kcal/h+2150 kcal/kWh (from 0-60% load)

Analysis of the effect of the higher steam conditions on heat consumption gives the following decreases, due to increases of—

pressure	13 to 56 atm abs ..	12%
	(170 to 782 p.s.i.g.)	
temperature ..	300° to 485°C	13%
	(572° to 905°F)	
final feed temp. ..	70° to 146°C	4%
	(158 to 295°F)	

Resultant relative heat consumption 0·88 × 0·87 × 0·96 = 73·5%

Hence reduction = 26·5%

The Suvilahti turbine, for the same efficiency and under the Salmisaari conditions, would thus show a nett heat consumption of—

$$2920 \times 0{\cdot}735 = 2150 \text{ kcal/kWh}$$
$$(11{,}587 \times 0.735 = 8531 \text{ B.Th.U/KWh})$$

The measured nett heat consumption of the 30 MW English Electric unit at Salmisaari was 2129 kcal/kWh (8448 B.Th.U/kWh), which is 1% better than the above figure. It is also better to the same extent than the measured heat consumption of the 50 MW ' Musil ' turbine operating at 105 atm abs (1480 p.s.i.g.) with reheat. It is evident therefore that in the 30 MW English Electric generating set at Salmisaari the Helsinki Municipality possesses a good turbine.

Gamma-Radiography in Industry

By D. J. GRIFFITHS, A.M.I.E.I., Works Radiologist, Stafford.

LARGELY AS A result of war-time requirements, and also because of insurance specifications, industrial radiography has become a valuable and widely-used method of non-destructive testing. The first major recognition of its worth was made in 1934 when Lloyd's Register of Shipping wrote radiographic inspection into their code for the approval of high-pressure fusion-welded vessels. In the years between 1939 and 1945, the aircraft industry called for greatly increased production, and radiography ensured that the vital need for reliability of components was not impaired by the greater output. To-day, less reliance is being placed upon 'safety factors' in design, and conditions of service have become much more demanding. Thus, the soundness of material is of vital importance.

The usual 400 kV industrial x-ray unit is capable of penetrating some four inches of steel within a reasonable exposure time, but in modern practice it is often necessary to examine far greater thicknesses than this. Advances in the design of x-ray tubes and ancillary equipment have culminated in the production of one-million volt and two-million volt radiographic units, which can adequately penetrate ten or twelve inches of steel. Unless repetitive examinations of thicknesses of this order are necessary however, the cost of purchase and installation of one of these units is prohibitive. The need for some alternative, cheaper method of examining occasional thick sections has long been realised, and attention was at first turned to the possibility of using the gamma-rays from radium. Recently, radioactive isotopes, obtained in the course of atomic energy work, have been used, and the demand for these is now steadily increasing.

Early use of Radium and Radon

In the year following Röntgen's discovery of x-radiation, the interest of scientific circles was still further aroused by the discovery, by Becquerel, that uranium compounds emit radiation which can penetrate opaque materials and blacken a photographic emulsion. A few years later came the separation of radium by Madame Curie and her husband.

Radium, and radon, the gas into which it decomposes, are still useful sources of radiation, although they have several disadvantages. Radium itself is very expensive, and suffers from the further limitation that quantities of sufficient strength for radiographic purposes are large in size, with the result that the sharpness, or definition, of the radiograph is poor. Radon, which, of the two, is the more powerful source of gamma-rays, when separated from radium and used alone avoids both these difficulties, but rapidly decreases in strength. In a little less than four days its intensity is reduced to half the original value, and the radiographic exposure has to be proportionately increased, so that the radon rapidly becomes too weak for

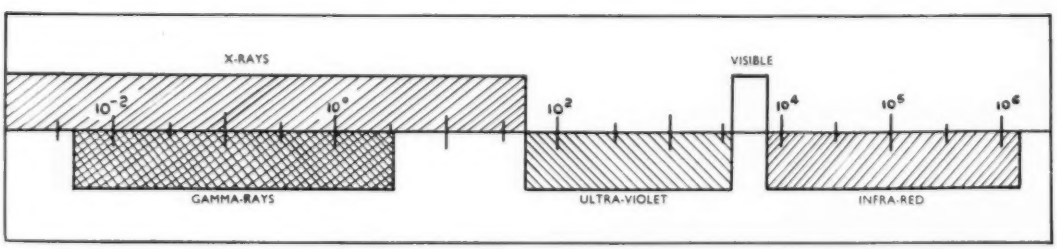


Fig. 1.—Portion of electromagnetic spectrum

industrial radiography ; its use depends upon the facilities for speedy supply.

Atomic energy work has now made possible the production of radioactive isotopes of various metals. These, being prolific emitters of gamma-rays, are being used in increasing numbers for the radiography of thick sections and dense materials.

Radioactive isotopes are in many ways preferable to either radium or radon for industrial radiographic work. They are produced by the Atomic Energy Research Establishment at Harwell, and their main advantage is that an isotope, together with an operating and storage container, and accessories, can be obtained for roughly one-tenth of the price of the usual industrial x-ray unit. Replacement and running costs are negligible.

Nature and Properties of Gamma-rays

Both x- and gamma-rays form part of the electromagnetic spectrum, as shown in Fig. 1, together with visible light, infra-red and ultra-violet rays. X-rays and gamma-rays are able to penetrate opaque materials because of the shortness of their wave-lengths, which, in the case of x-rays, range from 0·06 to 100 angstrom units. The wave-lengths of gamma-rays lie in the range between 0·01 and 1·4 angstrom units (1 angstrom unit $= 10^{-8}$ cm).

The practical importance of the wave-lengths of x- and gamma-ray radiation lies in the fact that the shorter the wave-length becomes the more penetrating are the rays. Gamma-rays, therefore, having a shorter wave-length than x-rays, will penetrate thicker sections of material.

Preparation of Radioactive Isotopes

The process of production of radioactive isotopes can best be explained by using as an example the isotope cobalt^{60}, which is one of the most useful in radiographic work.

Pure cobalt, $_{27}Co^{59}$, is bombarded in an atomic pile with slow neutrons, which enter the nuclei of the cobalt atoms, rendering them unstable. This causes each affected nucleus to disintegrate and, in so doing, an electron or beta particle (β) is emitted, followed by two gamma-rays (γ) with respective energies of 1·17 and 1·33 MeV. The loss of the electron raises the atomic number of the element by one, and it becomes nickel, $_{28}Ni^{60}$.

The reaction is :

$$_{27}Co^{59} + {}_{0}n^{1} \longrightarrow {}_{27}Co^{60} \text{ (during activation)}$$

and $_{27}Co^{60} \longrightarrow \beta + \gamma + \gamma + {}_{28}Ni^{60}$ (during breakdown).

The specific activity, or intensity per unit mass, of a radioactive isotope is measured in curies (C) or millicuries (mC). The curie expresses the number of nuclear disintegrations taking place per second, and the intensity of one curie ($3{\cdot}7 \times 10^{10}$ disintegrations per second) is equivalent to that of one gramme of radium.

Half-life Periods

The disintegration of radioactive nuclei is a natural phenomenon which cannot be retarded or accelerated. The length of time required for all atoms of an element to return to a stable condition varies enormously with the element and isotope concerned. It is clear, however, that as more and more nuclei become stable, the gamma-radiation emitted from the remainder will become proportionately less. For purposes of calculation, ' half-life ' periods for each isotope have been computed, the half-life being the length of time required for the original intensity to fall by one half. The half-life of radon is 3·8 days, that of cobalt^{60} 5·3 years. Iridium^{192}, another isotope useful in industrial radiographic work, has a half-life of 70 days.

Because a decrease in the intensity of a source necessitates a proportionate increase in exposure time, eventually the source becomes too weak for practical use. It is at this time that one of the advantages possessed by radioactive isotopes becomes apparent, for the source can be returned to the atomic pile and ' warmed up ', or reactivated. A cobalt^{60} isotope of four millimetres in diameter and 100 mC in intensity can be reactivated to 400 mC in approximately one year. The usual industrial practice is to use two sources alternately, one being reactivated at Harwell while the other is in use. The cobalt^{60} sources will last for three or four years without alternating, but in the case of iridium ^{192} the short half-life period necessitates a change of source at approximately five- or six-weekly intervals.

Sources used in Industry

The Atomic Energy Research Establishment provides many different types of radioactive isotopes, but in order to be useful for industrial radiography, certain requirements must be fulfilled. The source should be comparatively cheap, the half-life should be long enough to obviate any change in intensity during an exposure period, and the diameter of the source should be small, so that sharp radiographs, clearly revealing even small defects, will be obtained. The energy of the emitted radiation is another important factor. Radiation which is too penetrating will not reveal small flaws in the metal, for reasons which will become apparent later. On the other hand, radiation which is rather weak will be useful for only limited thicknesses.

The three sources mainly used in industrial work are iridium ^{192}, cobalt^{60}, and tantalum^{182}, which fulfil all the above requirements. Iridium^{192} emits less penetrating radiation than either cobalt or tantalum, and is useful for the examination of steel thicknesses from half an inch up to two and a half inches. Its penetrating power is roughly equivalent to that of a 400 kV x-ray unit.

Cobalt^{60} is useful for the examination of steel from two inches up to eight or nine inches thick, but takes rather a long time to activate. It is, nevertheless, a very common and really useful isotope for industrial radiography. Cobalt^{60} has a penetration approximately equivalent to that of a two million volt x-ray apparatus.

Tantalum^{182} is more speedily prepared than cobalt^{60}, and has roughly the same characteristics. It will emit gamma-rays capable of penetrating from two to six inches of steel, and there are in its spectrum some gamma-rays of lower penetration, which may be of advantage in the examination of thinner sections. The half-life of 120 days is rather short, and tantalum sources are only prepared at Harwell to order. In general industrial radiographic work iridium^{192} and cobalt^{60} can satisfactorily cope with the specimens usually encountered.

All three sources can be obtained in strengths sufficiently high for industrial work, in diameters as small as 2 mm, and thus excellent radiographic definition can be obtained. Some iridium sources can, in fact, be supplied with a diameter of only 1 mm, but as yet these are rather weak for radiographic purposes. It is expected, however, that in the future 1 mm diameter sources of quite a high strength will become available.

Uses of Gamma-rays

Although the various radioactive isotopes have been compared by quoting their penetration through steel, it will be realised that gamma-rays can be used for the examination of any comparatively dense metal. The major exception is lead, which because of its high density is an excellent absorber of both x- and gamma-rays, and therefore is valuable for protective purposes.

Castings of chromium-copper, brass, phosphor-bronze, and the gunmetals, produced in 'English Electric' foundries, are frequently subjected to examination. Excellent results are also being obtained in weld examinations. The gas-tight welding on hydrogen-cooled alternator stator frames is gammagraphed as a routine procedure, and the circumferential welds on Class I fusion-welded

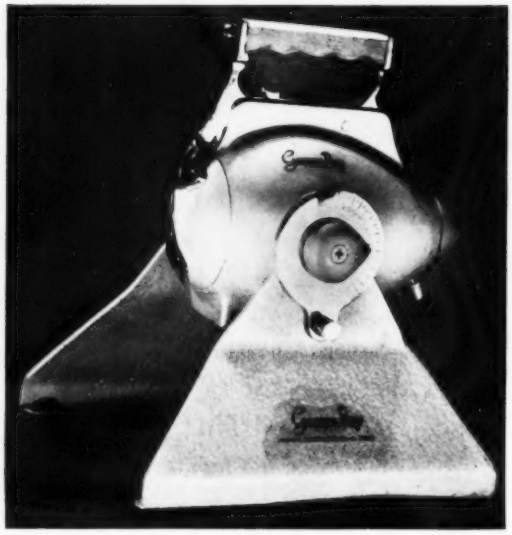


Fig. 2.—Exposure container for radioactive isotopes and radon

air-blast circuit-breaker receivers are subjected to gamma-ray examination. In this case, the gammagraphs are taken after the outer weld has been laid down and the inside plate machined through to the root of the weld in preparation for the inner seam. This particular application is valuable in that it determines with certainty that the preparation for the inside weld is satisfactory, and also enables any defects present in the outer weld to be removed. If, in the final examination of the completed weld, defects are found, it is obvious that they are located in the inner weld, and the problem of their removal is therefore simplified.

A particular advantage of radioactive isotopes is their extreme compactness and portability. Isotopes have, for example, been used inside the propeller tunnels of ships, at the top of radio towers, and even under water ; these are all impossible positions for an x-ray unit.

The dimensions of the typical isotope container illustrated in Fig. 2, which carries the source for the duration of the exposure, are 11″ × 11″ × 9″, and it weighs only 36 pounds. The isotope itself is mounted at the end of a rod of fifteen millimetres diameter, and can thus be inserted into extremely small apertures. In one instance gamma-rays detected a cracked weld which was inaccessible as far as any other method of non-destructive examination was concerned. The source had to be inserted through a one-inch diameter pipe, and the distance of the source from the film was limited to two inches, but a readable gammagraph was produced.

There have also been occasions when gamma-radiography has provided useful information regarding the internal construction of assemblies which had failed. A mercury-arc rectifier, which, when assembled, cannot be opened up without breaking a vacuum, is an example of this type of application. In these cases the overall depth of the specimen was considerably more than that normally met with in gamma-radiography, but although, inevitably, some detail was lost of the components nearest to the source, the gammagraphs in most cases revealed the cause of failure.

How Defects are Revealed

Fig. 3 shows diagrammatically the production of

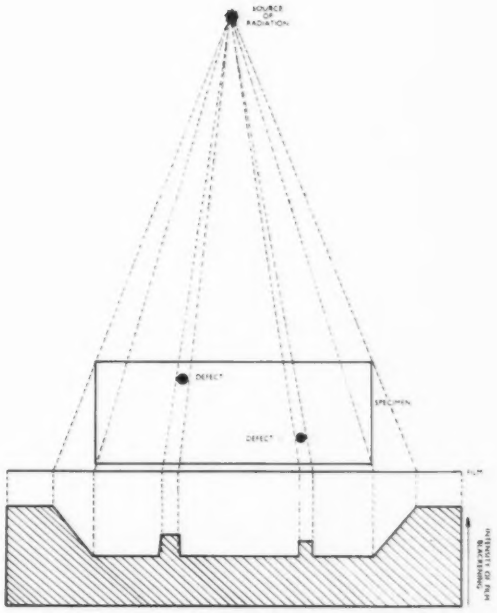


Fig. 3.—Diagrammatic representation of the principles of gamma-radiography

a radiograph with gamma-rays. The lower part of the diagram represents the degree of blackening of the film, and it will be seen that at the ends of the film, at points where no metal is shielding it from radiation, the blackening, or density, is very intense. At the edges of the specimen the density begins to decrease, until a level is reached at the point where the rays are penetrating the full section thickness. The image of defect I causes a local intensification of the blackening, as more rays are arriving at the film at this point. A similar effect is caused by defect II, but since this flaw is smaller, the intensification is less. As the first defect is near the top of the specimen, divergence of the rays after passing it causes a slight blurring of the image. Defect II, being closer to the film, has a sharper image since the beam divergence is not so great.

Very penetrating radiation will not reveal extremely small defects because the difference in the absorption of such radiation caused by a defect of this magnitude will be negligible, and no appreciable difference in the blackening of the film

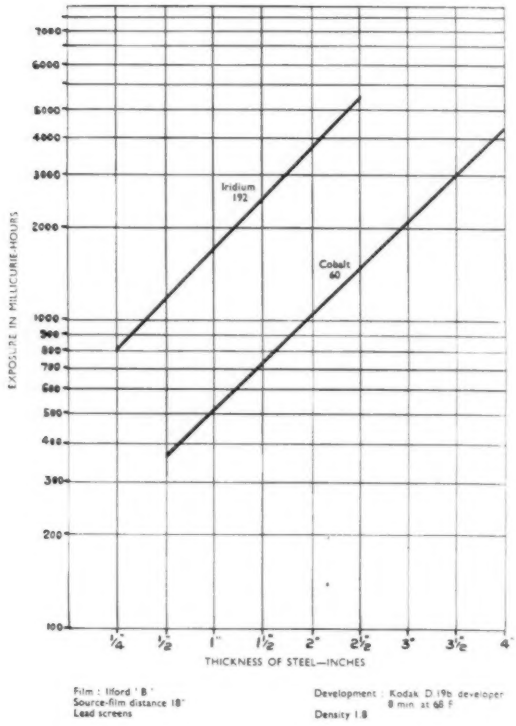


Fig. 4.—Typical exposure chart for Cobalt^{60} and Iridium^{192}

will result. In x-ray work this can be overcome by the use of a lower kilovoltage across the tube, thus propagating x-rays of longer wave-length and therefore less penetration. In gamma-radiography a similar result is achieved by careful choice of isotope.

Exposure Times

The intensity, as distinct from the penetrating power, of the radiation emitted from an x-ray tube can be ten times that received from a radioactive isotope when the radiating surfaces of both are of similar size, and therefore exposures with gamma-ray sources are much longer. In x-ray work, exposures are usually a matter of seconds or minutes, whereas, with a gamma-ray source, hours may be necessary, as will be seen from the exposure chart reproduced in Fig. 4.

This chart is typical of those produced for cobalt^{60} and iridium^{192} sources, and is intended for the examination of steel with the source at a distance of eighteen inches from the film. The exposures are marked off along the ordinate in millicurie-hours, which, as the term implies, are the product of the strength of the isotope in millicuries, and the exposure in hours. Since the exposure is inversely proportional to the strength of the source, this is a convenient way of expressing the exposure time. To use the chart, the point of intersection of the appropriate thickness with the

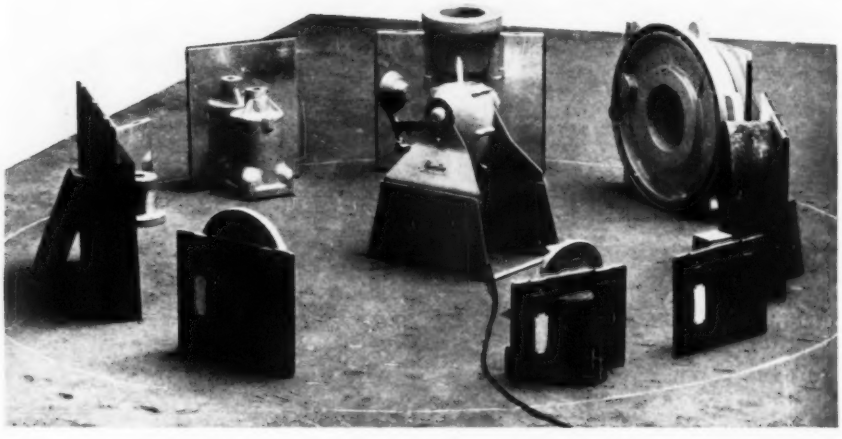


Fig. 5.—The 'panoramic' technique of gamma radiography

curve for the source in use is followed across to the left, and the millicurie-hours thus obtained divided by the strength of the source at the time of exposure. This latter figure is easily found from the decay curves supplied with each isotope. It will be seen that this type of exposure chart automatically takes into account the decay of the source in accordance with its half-life.

In common with visible light, the intensity of the radiation varies inversely with the square of the distance from the source. An increase in distance from 18″ to 27″ necessitates doubling the exposure time. At 36″ the exposure must be increased four-fold.

The lengthy exposures needed by gamma-ray sources may at first be considered a serious disadvantage, but in practice they have been found to be less inconvenient than they appear. Since the emission of gamma-rays is absolutely continuous, and no attention is required during an exposure, overnight and week-end shut-down periods can be profitably used for exposure purposes. Another method of reducing the effect of the long exposure times makes use of the fact that, unlike an x-ray tube, from which radiation is unidirectional, a gamma-ray source emits rays in all directions. With the source protruded from its container a ring of objects can be gammagraphed simultaneously, the source being positioned in the centre of the circle, as shown in Fig. 5. This ' panoramic ' technique is also very useful for the radiography of an entire circumferential weld, or the complete surface of a globular vessel, with one exposure.

Shorter exposures can of course be achieved by the use of a more powerful source. However, because of associated health hazards for personnel, these need greater shrouding with protective materials, and the weight and bulk is consequently increased. The use of a faster radiographic film also provides a limited answer, but the faster the film the larger become the grains of its emulsion, and a point is eventually reached when the size of the emulsion grains masks the finer details of the radiograph.

A further method of reducing exposure times consists of using two films, one behind the other, which are superimposed for viewing purposes. The increased film density thus obtained makes possible a reduction of about 40 per cent. in the exposure time.

Exposure Procedure

The exposure procedure with gamma-rays is very similar to that used in x-ray work. Since the sharpness of the images of defects is improved by an increase in the distance from the source to the film, this should be as large as possible with regard to a reasonable exposure time. Under normal conditions, the distance should never be less than six times the thickness of the metal, or serious distortion of the image may result, causing difficulties, or even errors, in interpretation.

The film is identified with the area of the specimen to which it relates by the use of lead letters, which are fastened with adhesive tape to the object before exposure. The approximate location of defects, also, can be determined in this way, should it be necessary to carry out repair work.

In general, the film and source are so placed that the rays pass through the metal normal to the surface. If any particular area is under suspicion the source is centred over this area. Excessive differences in thickness may be partially equalised by placing the source opposite to the thicker section, so that the rays passing through the thinner areas have to travel through the metal at an angle, thereby increasing their path. Specimens of varying thickness can be simultaneously examined by placing them at different distances from the source, so that the exposures for each will be the same.

Radiographs have a lower contrast when exposed by gamma-rays than when x-rays are used, and although at times this causes interpretation to be more difficult, it does allow for the satisfactory penetration of several different thicknesses of metal on one film. Figs. 6 and 7 illustrate this point quite clearly. In Fig. 6, x-rays have revealed the thinner parts of the electric pistol drill, but thicker sections such as the motor and the chuck have not been penetrated at all. In practice, an additional exposure would be necessary for these sections. Fig. 7, however, taken with cobalt^{60}, reveals details of the thicker parts quite clearly, and the structure of the thinner sections is still definable.

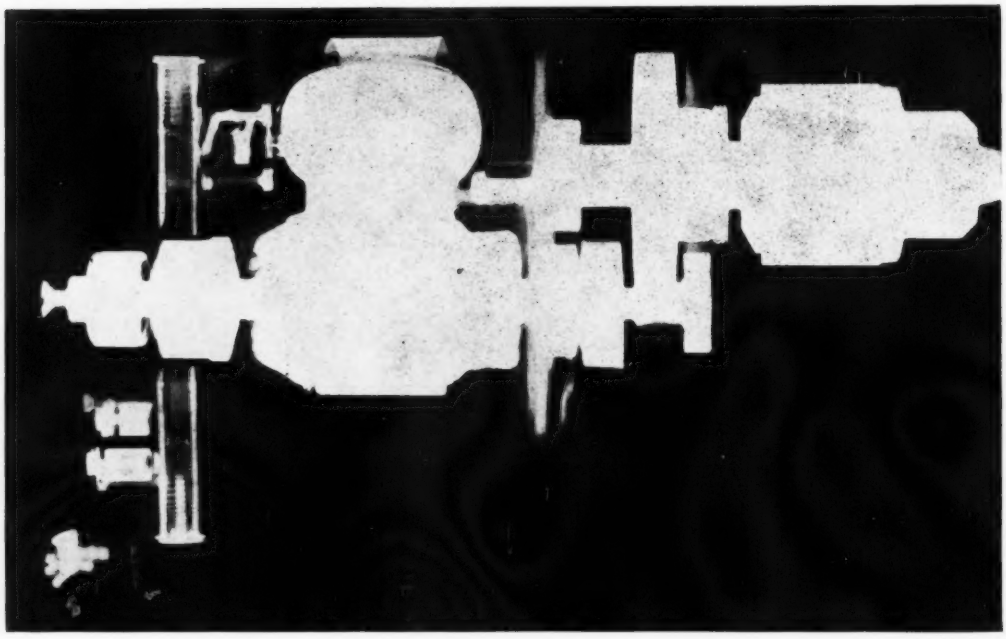


Fig. 6.—An electric pistol drill, radiographed with 120 kV x-rays

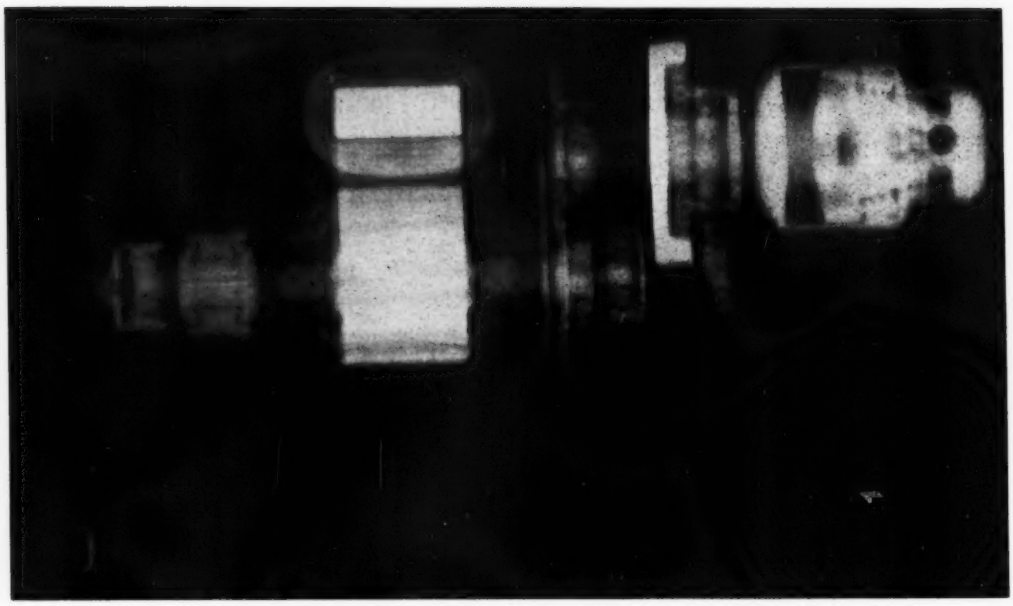


Fig. 7.—Gammagraph of an electric pistol drill, with Cobalt^{60}

Sensitivity of Flaw Detection

'Sensitivity of flaw detection' is a phrase commonly used in industrial radiography, and it means simply the dimensions of the smallest flaw that can be revealed on the film by a given radiographic technique. A sensitivity of 2 per cent. indicates that any defect with a depth in the plane of the beam of 2 per cent. or more of the total section thickness is visible on the film. This degree of sensitivity is usually considered adequate in x-ray work. In the majority of gamma-ray applications a sensitivity of this order can be obtained, providing a long source-film distance, a small diameter source, and a fine-grained film are used. A snug fit between the film and the object under examination is also necessary.

The radiographic sensitivity is assessed by the use of a step-wedge, made of the same metal as the specimen. Each step has one or more holes drilled through it. The thickness of one of the steps is 2 per cent. of the section thickness, and the drilled holes represent an artificial flaw of this depth. The step-wedge is placed in the position of worst sensitivity, that is, on the side of the specimen nearest the source, and towards one end of the section. If, under these conditions, the 2 per cent. step is visible on the gammagraph, then any flaw of similar size, or larger, in the metal itself will be equally visible.

A series of experiments was carried out by the author to determine the sensitivity of fault detection that could be expected in the gamma-radiography of various thicknesses of steel, under practical working conditions. A 400 mC cobalt^{60} isotope with a diameter of four millimetres was used. The steel thicknesses ranged from two inches to six inches, and artificial defects representing blowholes, cracks and lack of penetration were incorporated in the steel. The distance of the defects to the film was varied throughout the full thickness range of the metal during the series of exposures.

It was found that with this isotope a 2 per cent. sensitivity could be obtained for all thicknesses of steel up to four inches. Above this thickness, a source-film distance of 18″ gave a sensitivity of 3 per cent., but if the source was removed to 36″ from the film, the 2 per cent. sensitivity was restored. This distance, however, made the exposure for six inches of steel unduly long for practical work. With a source of two millimetres diameter the sensitivity would naturally be generally improved.

Interpretation

The art of interpretation of gammagraphs is one that is learned largely by experience. One important consideration is the quality and intensity of the illumination used for viewing the gammagraphs. The practice of holding up a radiograph to an electric bulb or a window for purposes of interpretation is thoroughly bad and should never be condoned. The colour of the viewing light should preferably be bluish-white, and the light should be evenly diffused over the entire viewing area. A high-intensity source of illumination, such as that provided by a photoflood bulb, is an advantage, and can be used for the examination of particularly dark areas of the radiograph. All extraneous light should be masked off by sliding shutters or curtains on the face of the viewing box ; this has an amazing effect on the clarity of the radiograph. Subdued lighting is preferable in the viewing room, but there should be no reflections from the surface of the radiograph.

The angle of the incident beam of radiation with the object, the thickness of the specimen, and the distance of the source from the film all affect the ultimate appearance of the defect in the radiograph, and these factors have to be considered during interpretation. Under optimum conditions, defects usually have a characteristic appearance in the radiograph, just as they have when seen visually, and the nature of a defect is seldom open to doubt. It is not always as easy, however, to decide whether or not the defect is likely to prove serious under service conditions. In addition to the location and size of the flaws, attention must be paid to their contour, and the proximity of other defects. Broadly speaking, globular flaws such as blowholes are likely to cause only moderate stress, but cracks and defects with jagged outlines can cause severe stress concentrations and are therefore much more serious. It is, however, impossible to be dogmatic, since even blowholes, if grouped together or in line formation, may cause failure.

The collaboration of metallurgist and designer

Fig. 8—Gammagraph of 3-inch thick weld, containing inclusions and porosity (Col·alt^{60})

Fig. 9 (right).—Blowholes in a 1½-inch thick leaded gunmetal casting (Iridium^{192})

may frequently be necessary to decide upon the seriousness of defects, the nature of which has been determined by the radiologist.

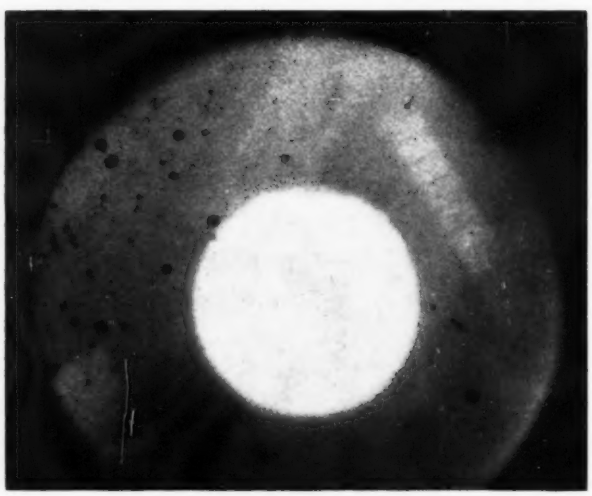
Weld Defects

The defects that can commonly be discovered in welds are gas pores and blowholes, cracks and pipes, slag inclusions, incomplete root penetration and lack of fusion. Gas pores and blowholes are both spherical cavities, differing only in size, and appear as round spots of varying size and density, but always darker than the surrounding metal. The defects may occur singly, in clusters, in linear formation, or may be randomly scattered throughout the weld. Linear porosity is often associated with incomplete root penetration.

Unfortunately, no guarantee can be given that either x-rays or gamma-rays will unfailingly reveal cracks. Their appearance, and the clarity of the image, depends to a great extent upon the direction of the beam of radiation in relation to the crack. If the beam of rays and the plane of the crack coincide, the defect will be revealed, but an angle of only a few degrees between the two may cause the defect to be missed.

This limitation is more likely to be troublesome in the case of castings, rather than welds. In a butt weld, in particular, both the beam and the majority of cracks are normal to the weld surface. A crack appears on a radiograph as a dark wavy line, possibly intermittent.

Fine piping can, under certain circumstances, give a similar image to a crack, but in doubtful cases the defects can be positively identified by repeating the gammagraph with the source displaced by three or four inches from its original position. The image of fine piping will change only slightly, whereas that of a crack will undergo



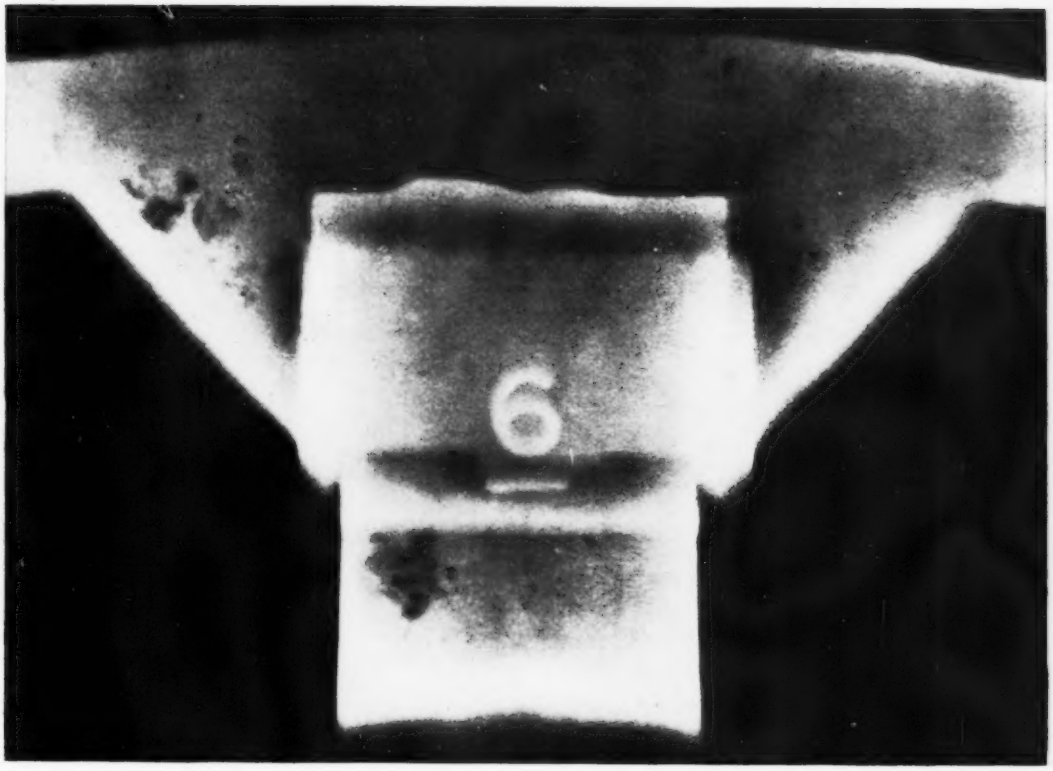


Fig. 10.—A 2½-inch thick chromium-copper casting, containing blowholes and inclusions (Cobalt⁶⁰)

radical alteration, and may even completely disappear. Piping which is not so fine appears as a dark shadow, the shape of which depends upon the angle of the pipe to the beam. If the pipe is end-on, a very dark, rounded shadow is produced. The shadow is elongated if the defect lies at an angle to the rays.

Slag inclusions appear as dark areas, irregular in both size and shape, and can be distributed throughout the weld in the same manner as porosity. They commonly have sharp or jagged edges which may act as stress raisers, and are therefore serious.

Lines of slag are often discovered in poor welding, and appear as dark lines of varying width. One or both edges may be wavy. The lines may occur singly, or two may run parallel to each other, and they can appear anywhere in the weld.

Incomplete root penetration is a very easily recognised defect, since it appears as a straight dark line along the centre of the weld image. The line may be continuous or intermittent, and can vary greatly in width. It is due to the failure of the first run of weld metal to fill the joint of the root. Incomplete root penetration is often associated with blowholes or slag inclusions.

A similar type of defect is that known as lack of fusion. This can occur at the side of the weld, between weld metal and parent metal, or between two runs of weld metal. Its image, again depending upon the orientation with the beam of radiation, appears as a dark line with clearly defined edges.

Fig. 8 is a gammagraph of a three-inch thick weld containing blowholes and inclusions.

Radiographic Standards for Welds

The metallurgists and radiologists of the various

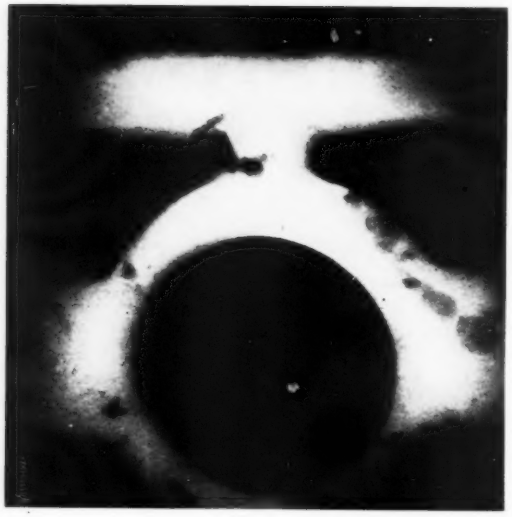


Fig. 11.—*Inclusions in a 3-inch thick chromium-copper casting (Cobalt*^{60})

sections of The English Electric Company have attempted to standardise the quality of Class A butt welds throughout the Company. The defects considered were cracks, porosity, slag inclusions and lack of penetration.

Radiographic standards for porosity were established for one-inch thick butt welds. Each set of standards consisted of nine radiographs, three referring to the size of the defect, three dealing with the number of blowholes per one-inch length of weld, and three with the distribution of the defects within the seam.

Of each three radiographs, one showed an

Fig. 12.—*Shrinkage defects in* $2\frac{1}{2}$*-inch thick leaded gun-metal (Cobalt*^{60})

' acceptable ' standard, one was ' borderline', and one 'unacceptable'. It was decided that for welds of two inches in thickness the original borderline standard should become acceptable, and for three-inch thick welds the unacceptable standard became acceptable. These modifications referred only to the standards for the number of defects ; the size and distribution standards remained unaltered. A maximum diameter of $\frac{1}{16}$ inch for acceptable blowholes was laid down.

A similar set of standards, acceptable, borderline and unacceptable, was prepared for lack of penetration in one-inch thick welds. Cracks were defined as being in no case acceptable.

An attempt was made to decide upon a set of radiographic standards for slag inclusions, but there were so many conditions to be considered for this type of flaw that it was found impossible. Instead, recourse was made to a mathematical formula instituted by the American Society of Mechanical Engineers in their Pressure Vessel Code, slightly modifying it for use within the Company. This modified formula laid down restrictions for the total length of inclusions expressed as a fraction of the plate thickness. Limitations regarding the size of isolated inclusions were also imposed.

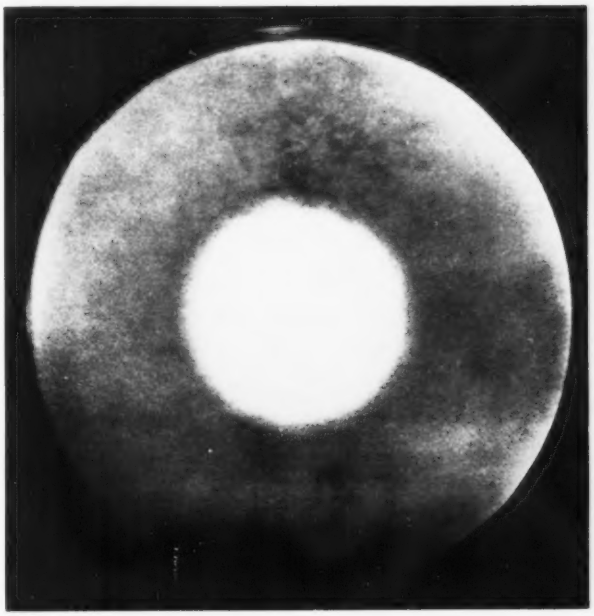


Fig. 13.—*Spongy area in* 1*-inch thick gun-metal pulley wheel, caused by shrinkage* (*Iridium*[192])

Casting Defects

The defects most commonly encountered in castings are blowholes, inclusions caused by sand, slag or foreign metal, shrinkage, and hot tears and cracks. Mis-runs and poorly fused chaplets are also occasionally found.

Blowholes appear in exactly the same manner as they do in welds, and may either be spherical or elongated. In cast-iron work, blowholes are apt to be associated with short cracks. Fig. 9 shows blowholes in a $1\frac{1}{2}$-inch thick leaded gun-metal casting. They are also present in the chromium-copper casting shown in Fig. 10, which is $2\frac{1}{2}$ inches in thickness.

Inclusions of sand or slag appear as dark areas of a lower density than blowholes, and are more diffuse in outline. They are irregular in shape, and may have jagged edges. Inclusions caused by sand are usually near the surface of the casting, and may be found by visual inspection. If the defect is due to the presence of foreign metal, the inclusion may appear lighter than the specimen, depending upon its comparative degree of density. Fig. 11 shows a chromium-copper casting three inches in thickness containing several inclusions, and this defect is also present in Fig. 10.

Shrinkage defects are one of the most common of casting flaws, and can appear in a variety of shapes. One appearance is shown in Fig. 12, where the defect assumes a network of fine dark lines spreading from a large cavity also caused by shrinkage. This casting was in leaded gun-metal, $2\frac{1}{2}$ inches in thickness. In Fig. 13 an area of mottled appearance is revealed. The shrinkage here is very fine and has formed spongy metal. In this particular instance blowholes are also present.

The phosphor-bronze casting, three inches thick, shown in Fig. 14, exhibits yet another characteristic

Fig. 14.—*Phosphor-bronze casting, 3 inches thick, containing shrinkage defects (Cobalt*^{60})

appearance of shrinkage ; that of dark, heavy streamers. The defect is again associated with porosity. In Fig. 15 the long pipe-like defect caused through shrinkage is clearly defined. This casting is in chromium-copper and is four inches thick.

Hot tears and cracks are similar in radiographic appearance, but in the majority of cases can be differentiated by the fact that cracks are usually straight and sharply defined, whereas tears are more filamentary, and have diffused branches of varying densities. Both defects are serious. Hot tears are difficult to reveal on a gammagraph.

Pouring metal at too low a temperature can result in the defect known as a mis-run. This appears as a large dark area on the gammagraph. Partly fused chaplets are represented on the film by dark outlines, often an accurate reproduction of the actual chaplet.

Surface Defects

In addition to the defects already mentioned, surface defects of appreciable depth are also likely to appear on the radiograph of either castings or welds. They can be revealed as either dark or light areas, depending upon whether the defect is a depression, or is due to excess metal, as in weld spatter or flash. In either case the images may easily be mistaken for defects within the metal and, to prevent this, notes should be made during radiography of any obvious surface defects. It is also good practice, when possible, to have the actual specimen available during interpretation.

Fig. 15.—*Pipe-like shrinkage defect in* 4*-inch thick chromium-copper casting (Cobalt*^{60})

Health Hazards

The danger to health associated with gamma-radiation has been brought home to the majority of people by the current public interest in atomic energy. The use of gamma-rays in industry necessitates stringent precautions, not only to safeguard the health of personnel actually using the radioactive isotopes, but also, when the sources are used in an open workshop, for the protection of other workers. Providing precautions are taken, however, the use of gamma-rays need have no harmful effects.

Because injuries to health caused by gamma-radiation are not immediately obvious, strict attention must be paid at all times to the rules for safety. Daily doses are cumulative, and the radiation can cause burns, blood changes, and derangement of certain internal organs. The hands, especially, are likely to be subjected to a higher rate of radiation than the rest of the body.

The changes in the blood are due to the action of the gamma-radiation in reducing the number of white cells, thus producing a form of anæmia. This induces severe lassitude and, if unchecked, may prove fatal. Madame Curie herself died as a result of radiation received during her work on radium. Large amounts of radiation received over short periods may cause damage to bone marrow.

Precautionary Measures

Fortunately, the effect of gamma-rays upon the blood can be detected in its initial stages by medical means, and each full-time worker with radioactive isotopes has a regular blood count. As even a mild form of the complaint lowers the resistance to disease, any person who is discovered to have a lowered white cell count would be removed for a time from x- or gamma-ray work.

In 1948 the British X-ray and Radium Protection Committee laid down a maximum permissible weekly dose of radiation which may be received without harm over an indefinite period. The basic unit of measurement of radiation is the röntgen, and the Committee stated that the maximum dose that could safely be received during one working week is 0·5 röntgen. Although radiation up to this maximum may be received without damage, it does not follow that smaller amounts need not be avoided, if at all possible. The lower the weekly dose received, the better it is for the individual concerned.

All full-time workers carry with them small pocket films provided by the National Physical Laboratory, which record the accumulated dose received by the body during the time they are worn. At regular intervals the films are sent to the Laboratory, where they are developed, the amount of radiation received by them determined, and a report prepared on each worker.

As an additional precaution, yielding more immediate results, each worker carries a pocket chamber which is, essentially, a small capacitor. The chamber is charged daily, and the radiation received during the day causes a proportional discharge. At the end of the day the amount of radiation received is measured on a suitably calibrated instrument.

Barrier materials, such as lead, lead impregnated plaster, concrete and brickwork are useful for protective purposes, but their efficacy decreases with their density. Walls are normally constructed of lead sheeting incorporated in brickwork or concrete blocks.

The storage of isotopes, particularly when more than one is held, necessitates careful planning and attention. The vicinity has to be chosen with regard to the proximity in all directions of other people. One method of storage is to keep the isotopes in a lead-lined container, which in turn is deposited in a pit lined with lead and concrete. The pit should be situated in a deserted area, as remote as possible from gangways and roads. It should be at least two feet deep, the cover lined with lead some two inches in thickness, and it should at all times be kept padlocked.

All the precautions so far discussed refer to the personnel who are working daily with radioactive sources. In industrial work, however, there may be frequent occasions when it is necessary to use a radioactive isotope in a workshop, or on a site where other workers are in close proximity.

In these cases, the area in which radiation is dangerous must be determined, and workpeople prevented from approaching closer to the isotope than is safe. The boundaries of the area can be found with the aid of a zone monitor, which,

working on the principle of the Geiger-Muller counter, indicates on a direct-reading scale the radiation being received at any one point.

Barricades or ropes should then be used to isolate the area for the duration of the exposure, and danger boards forbidding entrance prominently displayed. The boards should be coloured distinctively to contrast with the more usual white, red-lettered danger cards which may be used by other Work's departments to confine test areas and the like. The recommended shade for danger boards denoting radioactive areas is orange, the official atomic energy danger colour.

The use of shut-down hours for exposure purposes minimises any stoppage of work due to the isolation of the area, and has the additional advantage that there will be less risk of 'unobservant' persons ignoring the notices and entering the area.

Conclusion

The introduction of radioactive isotopes has considerably cut the cost of non-destructive testing, and it will be seen that gamma-rays have several other distinct advantages over x-ray generators. New and more powerful isotopes are frequently being announced, some of which will undoubtedly possess additional advantages for industrial radiography. Perhaps it is not too much to expect that isotopes will become more and more generally used, until the time arrives when our present x-ray units, honourably retired, will become museum pieces of interest to future generations.

The Napier 'Eland' Propeller-Turbine Aero Engine

THE NAPIER 'ELAND' IS A single-shaft propeller-turbine aero engine which develops 3,000 e.h.p. for a net dry weight of 1,575 lb. Of conventional layout and mechanically simple in design, the Eland incorporates many features which have enabled the engine weight to be kept to a minimum and which have resulted in an extremely clean overall shape with a total frontal area of only 7·1 sq ft. The economic fuel consumption together with the low specific weight make the engine suitable for both civil and military applications.

In the mechanical design of the engine particular attention has been given to the requirements of servicing and overhaul. The engine is divided into four major assemblies comprising reduction gear, compressor, combustion system and turbine. Each major assembly can be replaced individually so that, for example, when the turbine is removed, the reduction gear, compressor and combustion system need not be disturbed. The combustion chambers and burners are separately removable *in situ* for inspection or replacement, and free access is available to all engine accessories.

As a result of an intensive programme of

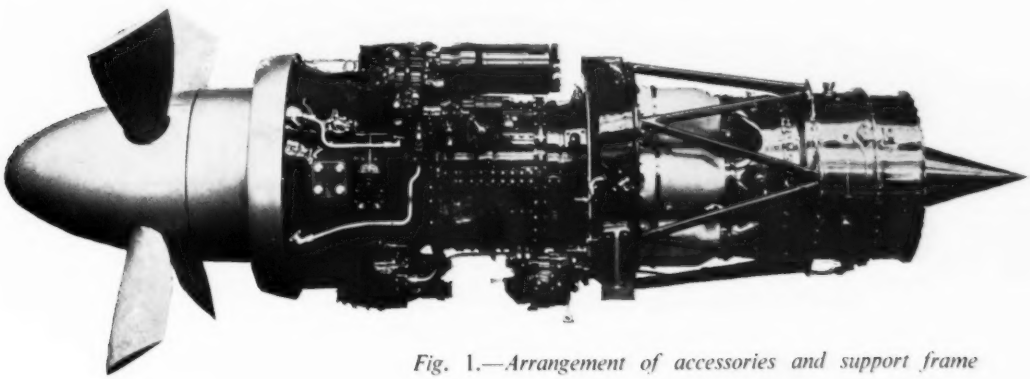


Fig. 1.—*Arrangement of accessories and support frame*

Fig. 2.—*Air intake assembly*

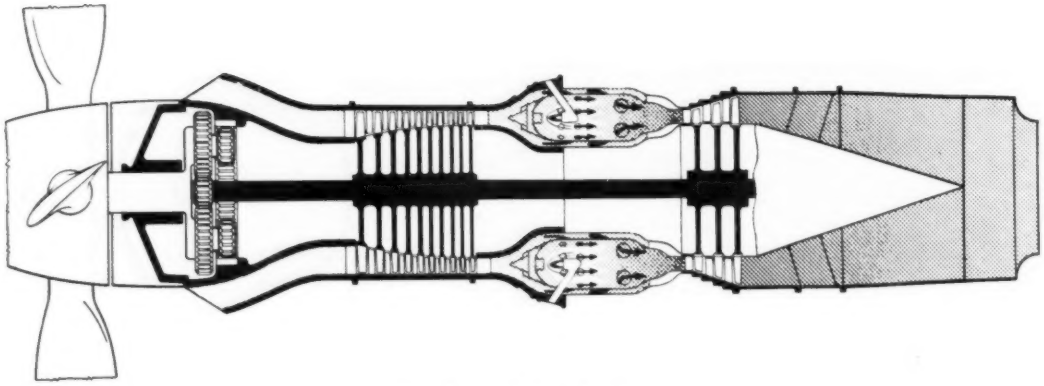


Fig. 3.—Gas flow diagram

research on axial compressors carried out over a number of years, the characteristics of the compressor are such that the margin between surge and the economic operating line gives the engine excellent handling qualities.

Full advantage of the compressor characteristics has been taken in the design of the controls, and the engine has a rapid surge-free acceleration. The control system also embodies devices giving instantaneous protection in emergencies.

Although these outstanding features enable the Eland to offer great economies in conventional applications, the engine is capable of considerable development and is sufficiently versatile to be utilised for other special purposes such as the Fairey 'Rotodyne'.

The Eland engine (Figs. 1 and 2) is designed for use with a single-rotation constant-speed propeller, the thrust of which is augmented by thrust from the jet. The engine consists of a ten-stage axial flow compressor delivering air to six combustion chambers in which fuel is atomized and burned continuously; the combustion products are delivered to a three-stage turbine and expelled to atmosphere through a propelling nozzle. The engine has a straight through flow path (Fig. 3) with no sudden changes in direction, thus ensuring maximum aerodynamic efficiency. The compressor and turbine are mounted co-axially and the propeller is driven through a reduction gear. Control of the engine is effected through an inter-connected fuel metering unit and propeller governor, operated by a single lever. Automatic compensation is provided for changes in forward speed and ambient temperature and pressure conditions.

Leading Particulars

General	
Maximum speed	12,500 r.p.m.
Direction of rotation (viewed from rear)	Left hand.
Reduction gear ratios	·0714 : 1, ·0838 : 1, ·0912 : 1, or ·0972 : 1
Overall Dimensions	
Maximum diameter	36$\frac{1}{16}$ in
Length (front of propeller shaft to turbine exit flange)	105$\frac{1}{8}$ in
Length (front of propeller shaft to end of turbine exit tail cone)	122$\frac{1}{4}$ in
Overall frontal area (including accessories)	7·1 sq ft
Weights	
Net dry weight less jet pipe (to EDM No. 25)	1,575 lb − 2½%
Complete with starter and propeller governor	1,661 lb
Jet pipe (per foot run)	7·6 lb
Propeller	
Type	Rotol or de Havilland hydraulic, four blades
Size	12 ft to 16 ft dia.
Fuel	
Wide cut gasoline	D.E.R.D. 2486
Aviation turbine fuel	D.E.R.D. 2482
Lubricating Oil	
Synthetic	D.E.R.D. 2487

Performance

Sea Level, Static (I.C.A.N. atmosphere)	
Take-off (12,500 r.p.m.)	2,690 s.h.p. at ·697 lb/s.h.p-hr 3,007 e.h.p. at ·624 lb/e.h.p-hr
Maximum continuous (12,000 r.p.m.)	2,070 s.h.p. at ·744 lb/s.h.p-hr 2,340 e.h.p. at ·659 lb/e.h.p-hr
Cruising (11,500 r.p.m.)	1,665 s.h.p. at ·781 lb/s.h.p-hr 1,890 e.h.p. at ·688 lb/e.h.p-hr
Altitude (30,000 ft, 400 m.p.h. T.A.S., I.C.A.N. atmosphere)	
Operational necessity (12,500 r.p.m.)	1,575 s.h.p. at ·554 lb/s.h.p-hr 1,880 e.h.p. at ·463 lb/e.h.p-hr

Maximum continuous (12,000 r.p.m.) ..	1,325 s.h.p. at ·566 lb/s.h.p-hr 1,570 e.h.p. at ·478 lb/e.h.p-hr
Cruising (11,500 r.p.m.)	1,130 s.h.p. at ·573 lb/s.h.p-hr 1,310 e.h.p. at ·493 lb/e.h.p-hr
Oil Consumption (cruising r.p.m.)	1 pint/hr

Further details are given in the Performance Appendix to this article.

Reduction Gear

The reduction gear (Fig. 4) has a low noise level and a high mechanical efficiency. These important qualities result from the use of a compound-layshaft epicyclic gear train which incorporates a hydraulic torque-meter. Due to the construction of the torque-meter the gearing is not mechanically fixed to the casing and this, together with other self-centring devices, reduces vibration to a minimum and considerably improves transmission. Alternative reduction gear ratios are available to suit different installations.

A magnesium casting houses the reduction gear and incorporates the air intake.

From the compressor, drive is imparted through a quill shaft to a high-speed input pinion supported at the rear end by a ball bearing, and at the front by a roller bearing. The pinion drives three planet gears having integral layshafts, each mounted on two roller bearings and carrying a planet pinion meshed with the internal annulus gear.

The combined planet gear and layshaft assembly is carried on roller bearings in the two halves of a carrier which is integral with the propeller shaft. The carrier is supported at the front by a roller bearing, and at the rear by a ball and roller bearing in the reduction gear casing. The ball bearing absorbs the propeller thrust.

Oil is delivered to the propeller hub through a feed in the propeller shaft and a transfer bearing mounted in the nose piece of the casing on rubber rings. The rings act as an oil seal and, in addition, prevent any load from being taken by the transfer bearing instead of the roller bearing.

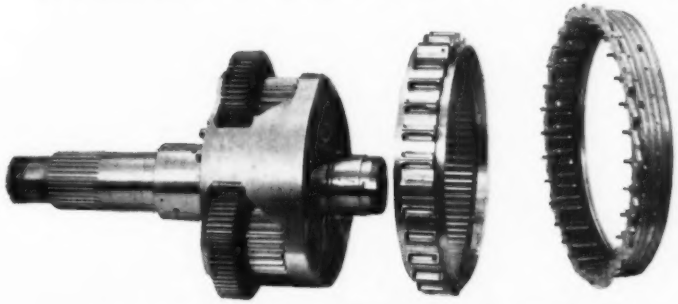


Fig. 4.—Reduction gear and torque-meter assembly

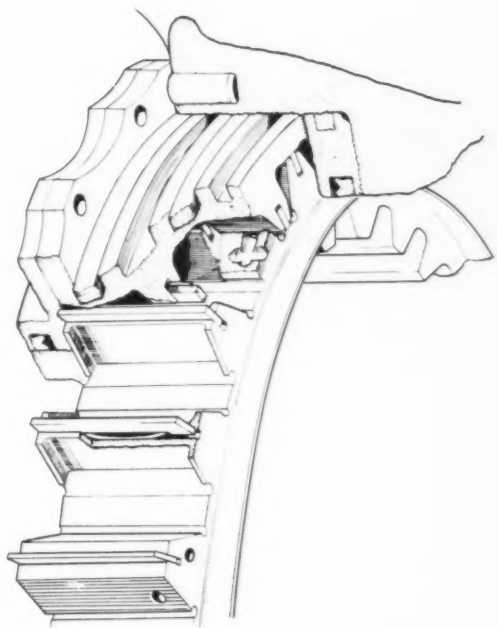


Fig. 5.—Torque-meter, showing arrangement of sealing vanes

At the rear end of the propeller shaft a bevel gear drives the oil pump assembly on the bottom cover ; the accessories on the top cover are driven by a similar gear on the compressor shaft.

Torque-meter

The torque-meter (Fig. 5), which is built into the reduction gear annulus gear, consists of an annulus gear and a torque ring, each having several vane-shaped members carrying spring-loaded sealing vanes. The annulus gear is located inside the torque ring so that the vane-shaped members of each

are interposed and spring-loaded against the annular walls between the opposite members by the sealing vanes. The spaces between the vane-shaped members form the high and low pressure chambers of the torque-meter and allow peripheral movement of the annulus gear. During normal operation, oil is supplied by a high pressure pump through inlet ports (Fig. 6) to the high pressure balancing chambers, and leaks across the sides of the vanes to fill the low pressure chambers. The high and low pressure chambers are separately interconnected by annular passages, and drain oil escapes through exhaust ports in the torque ring front cover to the engine sump.

As the torque increases on the annulus gear, the vanes move in relation to those on the torque ring, increasing the inlet port area and thereby increasing the oil pressure in the high pressure chambers until the pressure is sufficient to balance the torque. Movement of the annulus gear also

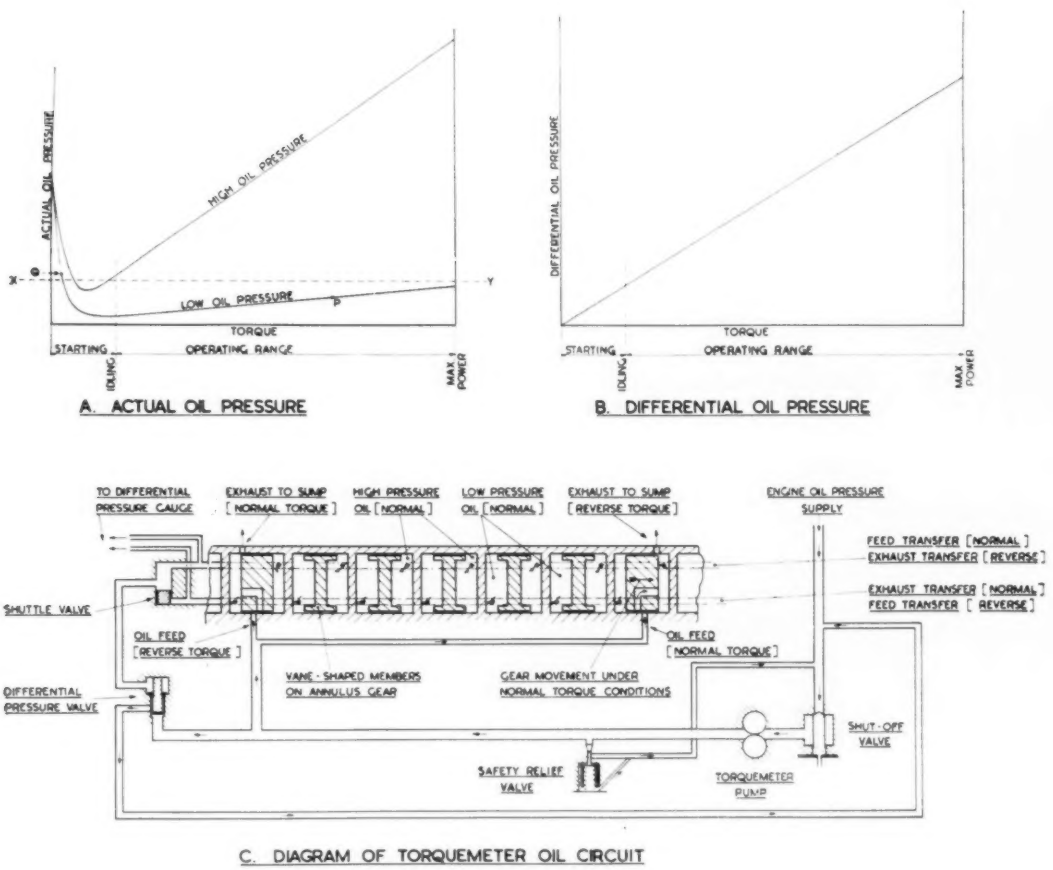


Fig. 6.—Torque-meter vanes and porting arrangement

increases the exhaust port area to facilitate drainage of the now greater leakage of oil from the low pressure chambers.

In the reversed torque condition, the ports in use for normal torque are closed by the relative movement of the annulus gear and torque ring, and other ports are uncovered to reverse the functions of the high and low pressure chambers. To obtain normal torque function, a shuttle valve is incorporated in the system so that high pressure oil is still fed to the differential pressure valve.

By suitable connections to the pressure balancing chambers the torque-meter can be used to give signals for operating safeguard devices in the event of component failure.

From the curves in Fig. 6 it will be noted that

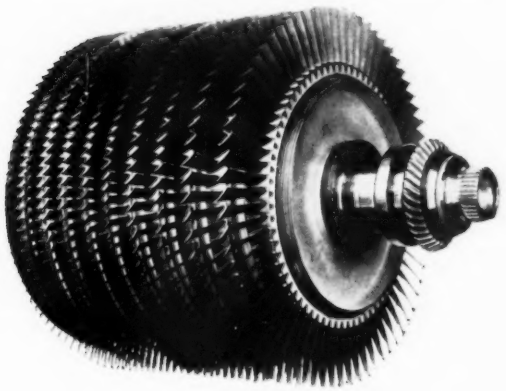


Fig. 7.—Compressor rotor

although the differential pressure signal from the torque-meter is linear with torque, the low pressure signal has its peak at zero torque. This is a feature of the porting design. It will be realised, therefore, that if failure occurs, the torque-meter low pressure signal will alter from a point such as P to a value Q. The safeguard unit consists of an arrangement which moves to the 'guarding' position when the low pressure is above the level XY. The safeguard unit is rendered inoperative by a cock during starting and running up.

Engine tests have consistently shown that the accuracy of the torque-meter over the normal power range is within $\pm$ 1% of the calibrated dynamometer readings.

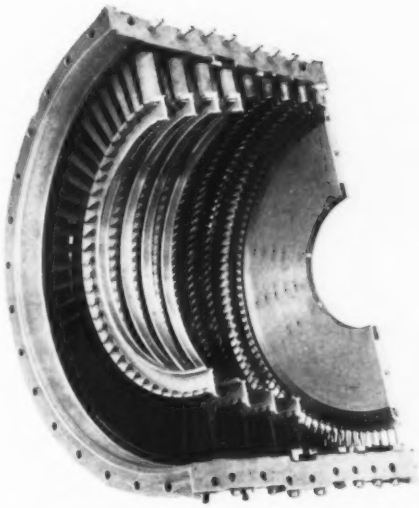


Fig. 8.—Compressor half-casing and stators

Air Intake (Anti-iced)

Air is delivered to the compressor through an annular, forward facing intake which surrounds the reduction gear casing immediately behind the propeller and is designed to take full advantage of ram effect at forward speed.

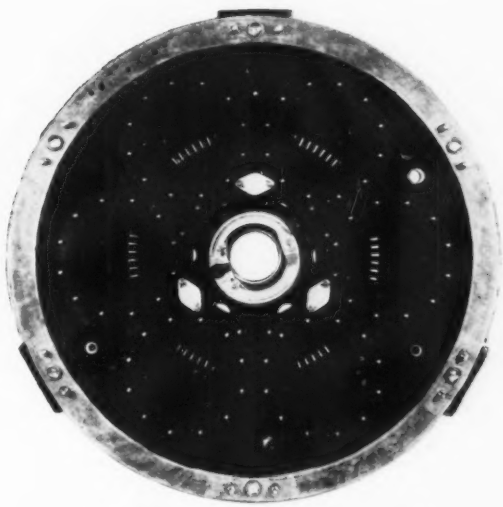


Fig. 9.—Rear view of support plate

The intake, in common with all other gas passages, has been flow-tested and developed for maximum efficiency before incorporation in the final design.

Protection against icing of the intake and compressor inlet has been given careful study. The inner wall of the intake is heated by reduction-gear oil splashed on the casings. Jackets have been designed for the outer wall of the intake through which reduction-gear scavenge oil is circulated before being returned to the cooler. This scavenge oil is also circulated through the noses of the six spats in the intake, which house the accessory drives and other essential services. The compressor inlet guide vanes are anti-iced by air tapped from a suitable stage in the compressor ; the air heats both leading and trailing edges of the vanes before exhausting into the main stream at the inner diameter.

Compressor

Compressors to suit an engine of given mass flow can vary between low hub/tip ratio, high speed, small diameter designs, and high hub/tip ratio, low speed, large diameter designs. In turbo-prop applications the former, although giving a lighter compressor, requires a larger reduction gear ratio and heavier gear box. The final design should therefore be a compromise to obtain the minimum engine weight. For this reason the Eland compressor has been designed for a medium hub/tip ratio of 0·7.

The compressor characteristics obtained give optimum efficiencies on the engine operating line which is well removed from surge. The margin from surge is further increased at low engine speeds by the use of variable inlet guide vanes, and as a result extremely good engine handling and acceleration responses are obtained without danger of surge. The inlet guide vanes are controlled by a speed-sensing servo unit.

A design pressure ratio of 7·0/1 has been achieved at 31 lb/sec mass flow for the take-off rating with only ten stages of blading.

The compressor is of simple construction comprising a disc and shaft-type rotor (Fig. 7) with two half-casings to which are bolted the stator rings (Fig. 8).

Aluminium-bronze blades are used throughout, and all the rotor blades are secured by fir tree roots to the compressor discs (see Fig. 7). These in turn are located over flank fitting splines to a hollow rotor shaft of S107 steel. For stages 1 to 7 the rotor discs are of aluminium and the remainder are of steel. The stators, which are of shrouded construction for the first four stages and cantilever for the remainder, are contained in the two halves of the L51 alloy compressor casing (see Fig. 8).

A ball and roller bearing at the front and a roller bearing at the rear support the compressor rotor shaft which is connected to the turbine by a gear-type coupling.

To prevent 'windmilling' while the aircraft is on the ground, a parking brake is fitted to the rear end of the compressor shaft (see Fig. 9).

Support Plate

Provision is made for mounting the engine from

Fig. 10.—*Combustion chamber*

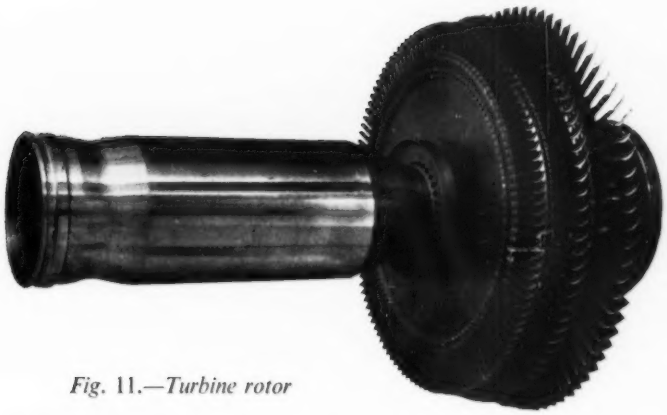


Fig. 11.—*Turbine rotor*

three pads on a support plate situated at the rear of the compressor. This casting in Z.T.1 light alloy (Fig. 9) includes the diffuser, between the compressor and combustion chambers, and an internally cast annulus into which air is bled from the diffuser for turbine cooling and cabin pressurization purposes.

Combustion Chambers

The combustion system, designed in conjunction with Messrs. Joseph Lucas Ltd., comprises six tubular-type chambers fitted with upstream injection burners. Each chamber and burner (Fig. 10) can be separately removed *in situ* without dismantling any other engine part. To facilitate withdrawal through the turbine frame, each chamber is secured at both ends by clamping rings.

Outer casings are fabricated in S.84 material, and the flame tubes in D.T.D. 703. High energy spark ignition plugs are provided in two of the combustion chambers from which the flame is propagated to the remainder by interconnectors. The use of upstream injection-type burners not only reduces the overall length of the system but gives good combustion at very high air/fuel ratios.

The engine operates satisfactorily on either kerosine or wide-cut type fuels.

Turbine

For a turbo-prop engine it is necessary to extract as much power as possible from the turbine to give maximum shaft output. The available expansion ratio is fixed by the compressor pressure ratio and the back pressure imposed by the jet pipe and nozzle. To reduce the back pressure the final jet velocity is kept low relative to the turbine exit

Fig. 12.—*Turbine nozzle assembly, stage* 1

Fig. 13.—*Turbine nozzle assembly, stage* 2

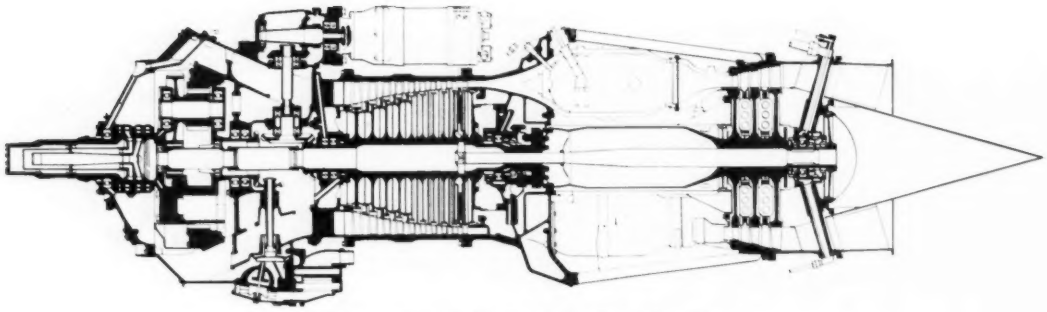


Fig. 14.—*Longitudinal section through engine*

velocity. To achieve the maximum output from the turbine, without excessive weight penalty, a three-stage reaction type turbine has been designed for the Eland at an expansion ratio of 5·5/1, with zero swirl to minimise jet pipe loss and turbine back pressure.

The turbine comprises three separate bladed rotor discs mounted on a shaft and carried in a fabricated casing which contains the three nozzle assemblies.

The rotor discs (Fig. 11), of H40 material, are mounted over flank fitting splines on the turbine shaft which is supported at the rear by a ball bearing and at the front by the gear-type coupling driving the compressor.

The combined rotor assembly (compressor and turbine) is mounted on three bearings and so arranged that the gyro-couples at the centre bearing are in general cancelled.

The rotor blades, which are of Nimonic 90 in stage 1, and Nimonic 80A in stages 2 and 3, are secured to the discs by fir tree roots.

The blades are so fitted in the disc that a limited amount of tip rock is obtained. This allows for the differential expansion of the blades and discs, relieves root stresses and ensures a large measure of vibration damping.

The nozzle blades are hollow and cast in X40 material, but the first-stage blades (Fig. 12), which are secured by inner and outer rings, differ from stages two and three which have inner and outer platforms and are bolted to the external casing. The inter-stage seal plates (Figs. 13 and 14), which carry seals at the inner diameter and cooling scrolls on each face, are mounted from the nozzle rings by swinging links attached to several of the blade roots. This arrangement allows for differential expansion and ensures concentricity of the seals under operating conditions.

Engine Cooling, Pressure Balancing and Sealing

Air is bled from the compressor to cool the turbine rotor discs, to supply air to the turbine and compressor balance pistons, to cool the compressor rear bearing and turbine bearing and to supply air to the inlet guide vanes to give protection against icing (Fig. 14).

The front face of the first-stage turbine rotor is cooled by compressor exit air, tapped from the diffuser. The air passes through the support plate annulus and is taken by three tubes to an annular chamber forward of the turbine. From here it flows between the front face of the disc and the front seal plate, through a scroll attached to the seal plate, and exhausts across the rotor blade roots to the trailing edge. The object of this scroll is to lengthen the path of the cooling air up the face of the disc.

Further air is tapped from stage 9 of the compressor, and passes into the hollow shaft through a static shroud. This shroud contains vanes which remove the free vortex flow which would otherwise exist in the air, and thereby increases the static pressure available. The rear face of stage 1 disc, both faces of stage 2 disc and the front face of stage 3 disc are cooled by the air from this supply passing through scrolls on the inter-stage seal plates. Air also passes out of the rear end of the

shaft to pressurise the turbine balance piston chamber.

The turbine bearing and the rear face of the last stage turbine disc are cooled in series with air taken externally through a pipe and filter from stage 4 of the compressor. Tappings from the filter supply the compressor rear bearing with cooling air, and pressurize the seals on the airscrew and accessory bearings.

To heat the inlet guide vanes and to supply the compressor balance piston, air is taken forward through the hollow shaft from stage 5 of the compressor. No vortex breaker is fitted in this system as the mass flow and pressure required are relatively low.

Jet Pipe and Accessories

Both the inner cone and the jet pipe, which is fitted with a propelling nozzle, are of Nimonic 75.

The engine accessories are mounted on the reduction gear casing, disposed in two groups around the compressor (Fig. 16), and are readily accessible for servicing.

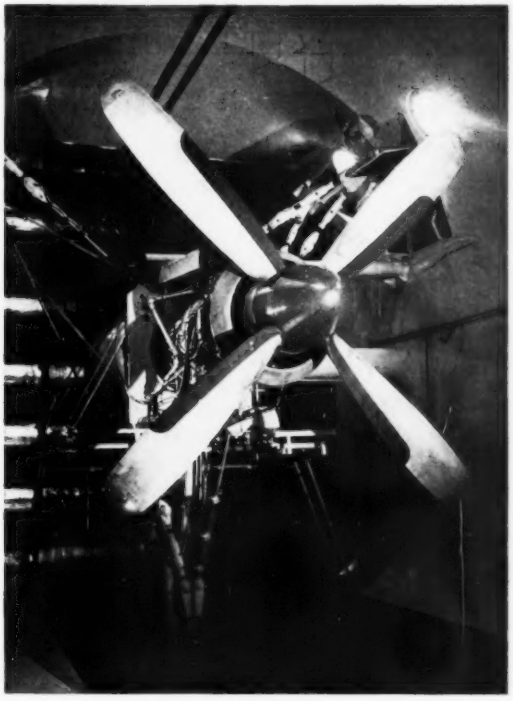


Fig. 15.—*Engine on test bed*

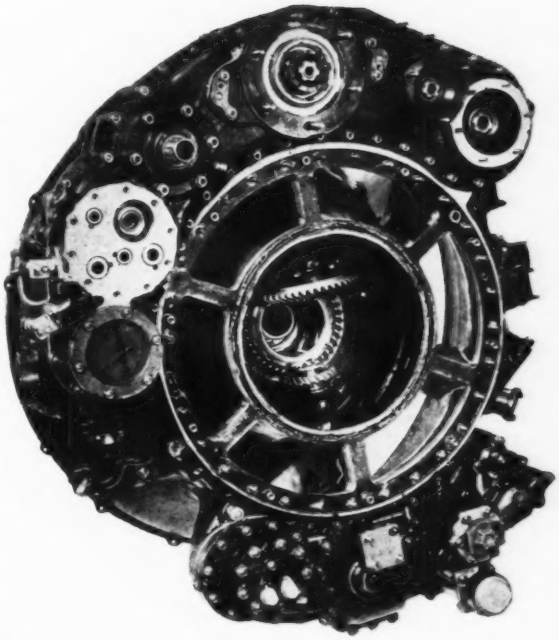


Fig. 16.—*Top and bottom accessory drives*

Of these, the fuel pump, tachometer, propeller governor, synchronizing alternator and an aircraft accessory gear-box drive shaft capable of transmitting 250 s.h.p., are mounted on the top of the casing and are driven by a spiral bevel gear from the front end of the compressor shaft. The design of this bevel drive is unusual in that the thrust is taken by locating cones on each gear, which help to ensure correct meshing, simplify fitting, and avoid the need for an additional thrust bearing.

At the bottom of the casing the pressure oil pump, torque-meter pump and scavenge pumps are all driven from the propeller shaft by spiral bevel gears.

A Rotax electric starter is mounted above the front end of the compressor, and motors the engine through the accessory gear-box drive. Development is proceeding on alternative types of starting equipment.

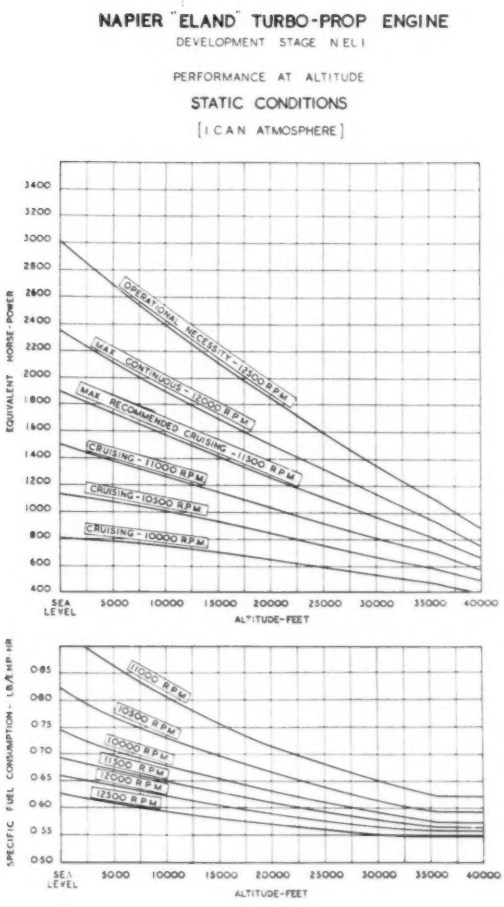


Fig. 17.—Altitude performance, static conditions

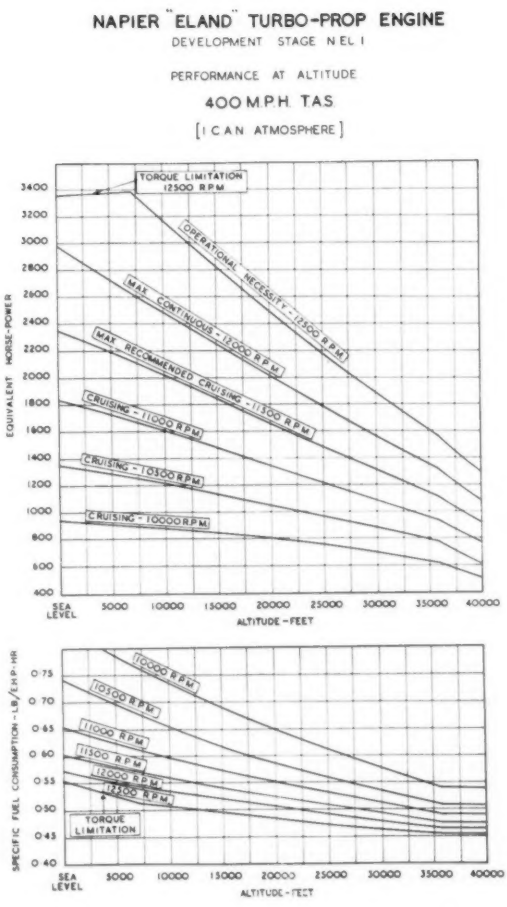


Fig. 18.—Altitude performance, 400 m.p.h.

Control

Control of the engine is effected by a single lever operating an interconnected propeller governor and Napier fuel metering unit which automatically compensates for changes in forward speed and ambient temperature and pressure conditions. An acceleration control is included in the unit to prevent overfuelling and surging of the engine during acceleration. The fuel metering unit is reset by a two-position lever in the cockpit when compressor air is taken from the support plate for cabin pressurization.

A variable-datum turbine inlet temperature control, a maximum torque limitation device, automatic pitch coarsening, and an inlet guide vane control which is responsive to engine speed, are also fitted.

Lubrication

The engine is supplied with oil from a pressure pump at 80 lb/sq. in. which, through a filter, delivers oil to the bearings, gears, torque-meter pump, and 'Purolator' filter feeding the propeller governor. The pressure pump incorporates a relief valve which by-passes excess oil, and a static head valve, situated between the pump and filter, prevents

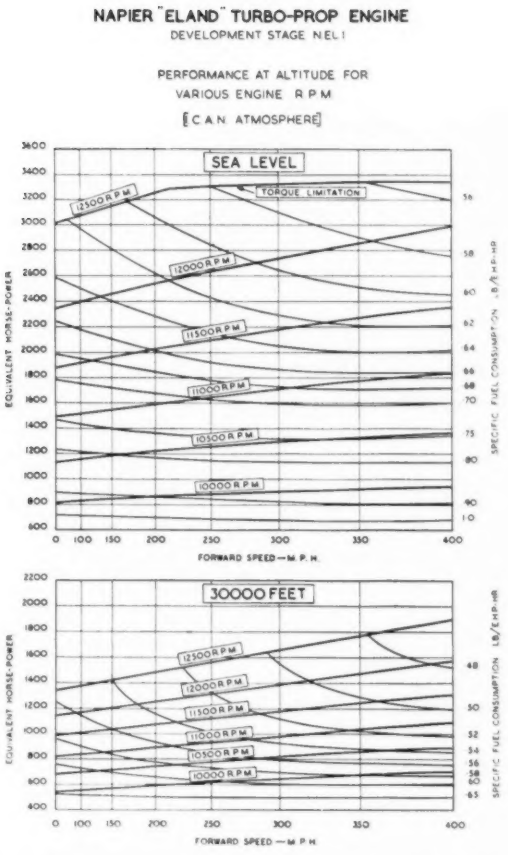


Fig. 19.—*Performance at various forward speeds, sea level and* 30,000 *feet*

flooding of the engine by oil from the tank under shut-down conditions.

Lubrication of the reduction gearing is effected by six sparge-type jets mounted on the planet carrier, and by impinging jets which feed the planet shaft bearings ; the high-speed pinion bearings and propeller shaft front bearings are splash lubricated. Calibrated jets supply oil to the compressor and turbine shaft bearings and to the rear bearing on the propeller shaft. The accessory drive gears and bearings are lubricated by splash oil and calibrated jets.

Engine scavenging is effected by a gear-type pump which returns the oil from the sump to the tank through a de-aerator and oil-heated jackets on the intake casing. Both compressor and turbine bearings are independently scavenged by vane-type pumps which return the oil to the engine sump, and which ensure efficient functioning during aircraft manoeuvres at all altitudes.

The reduction gear chamber is vented through a centrifugal impeller-type breather which separates the oil from the air before exhausting the air to atmosphere.

PERFORMANCE APPENDIX

(See also Figs. 17, 18 and 19)

T.A.S. m.p.h.	Altitude feet	Engine r.p.m.	S.H.P.	Net Jet Thrust lb	Fuel Cons. lb/hr	Spec. Fuel Cons. lb/ e.h.p.-hr
Operational Necessity						
Static	S.L.	12,500	2,690	825	1,875	·624
400	S.L.	12,500	2,900	560	1,861	·555
Static	10,000	12,500	2,165	635	1,421	·593
400	10,000	12,500	2,710	340	1,606	·506
Static	20,000	12,500	1,665	475	1,049	·567
400	20,000	12,500	2,105	290	1,203	·483
Static	30,000	12,500	1,210	345	748	·550
400	30,000	12,500	1,575	240	872	·463
Maximum Continuous						
Static	S.L.	12,000	2,070	700	1,545	·659
400	S.L.	12,000	2,640	255	1,697	·569
Static	10,000	12,000	1,705	545	1,186	·621
400	10,000	12,000	2,160	240	1,326	·534
Static	20,000	12,000	1,360	415	892	·587
400	20,000	12,000	1,720	220	1,015	·503
Static	30,000	12,000	1,025	305	650	·566
400	30,000	12,000	1,325	195	752	·478
Typical Cruising						
Static	S.L.	11,500	1,665	585	1,300	·688
400	S.L.	11,500	2,160	150	1,430	·607
Static	10,000	11,500	1,395	460	1,019	·646
400	10,000	11,500	1,800	160	1,132	·560
Static	20,000	11,500	1,115	355	774	·613
400	20,000	11,500	1,445	155	864	·526
Static	30,000	11,500	855	260	569	·578
400	30,000	11,500	1,130	140	647	·493

Plastics in the Company's Service

By M. FUZZARD, New Development and Process Department, Bradford.

THE TERM 'Plastics' has, for a considerable time, covered a very varied and widening field, but due to unscrupulous applications it has not always enjoyed a good reputation.

The vast number of components being marketed nowadays testifies to the versatile nature of the group of materials as a whole, but the technical applications within The English Electric Company are purely a matter of a specific material for a specific component. The Company utilises an increasing amount of plastics, behind which lie an enormous amount of research and development in proving reliability in service conditions. These conditions vary as much as the Company's products, and the plastics must be dependable in all circumstances, including overseas service and the rigorous requirements of modern production.

The wide range of applications of plastics by the Company, and the expanding usefulness of its Plastics Department, will be appreciated from the following description of some of the materials, production methods and products, which also indicates deciding and limiting factors.

Materials

There are two main types of plastic moulding mediums, the thermo-setting and the thermo-plastic groups.

THERMO-SETTING GROUP

This group comprises the type usually referred to as 'bakelite' and constitutes the normal black, brown or walnut components which are made by process into a hard infusible mass. This type once manufactured cannot be re-utilised.

The principal representatives of this group are phenol formaldehyde, and the type that allows gayer colours, urea formaldehyde, with several 'specials' such as melomine now famous as a substitute for conventional tableware, and the heat resisting alkyds. Tables I and II give the physical properties of two typical moulding powders.

Thermo-setting resins resulted mainly from the work of Dr. L. H. Baekeland, which led to the commercial adoption of moulding powders as utilised in modern production. Formaldehyde is the most important raw material, being used practically throughout the thermo-setting group, and it is upon the reactivity of formaldehyde that the heat hardening property of this type depends. Without going into the chemical or physical aspect of the reactive chain, an indication of the action of heat and pressure can be given.

Formaldehyde is a gas at normal temperature and is used commercially as formalin. It is the principal aldehyde which will react with phenols to give an economic thermo-setting resin, and by reacting formaldehyde with phenol and a catylist, to speed up reaction, a resin is obtained. There are three stages to these resins dependent on the ratio of phenol to formaldehyde. Initially the resin is thermo-plastic and soluble in some solvents; the second stage produces a resin which will soften but not melt on heating; the third stage takes place in the actual moulding process, when the resin becomes thermo-set and insoluble.

Commercially, the final product is brought about by reacting phenol and formaldehyde in special stills to give molecular ratios of approximately 1:1. A catylist is added to speed up reaction, and with production control the stills take the resin to stage two mentioned earlier. At this stage the resin is treated to influence the final product, by adding suitable fillers, pigments, lubricant, and a suitable formaldehyde containing substance such as hexamethylene tetramine which gives the addition necessary to cause complete 'cure' during the moulding stage. This mix is rolled on heated rollers to ensure final mixing and advancement to moulding stage, and it is then ground ready for use.

TABLE I

Physical Properties of a Typical Phenolic High Dielectric Moulding Powder, Wood-filled

Special Properties	Mechanical properties similar to general purpose type but superior in surface and volume resistivity and in dielectric strength at 90° C. Electrical properties impaired by moisture in powder, which must be kept dry before moulding.
Colours	Black, brown, walnut and colours.
Moulding Conditions	
Temperature	150-170° C (302-338° F)
Pressure	1-2 tons/sq in
Rate of Cure	
Cup cure	65 seconds
Minimum cure for ¼ in. thickness at 160° C	130 seconds
Powder Properties	
Bulk density	0·6-0·7 gm/c.c.
Bulk factor	2·0-2·3
Pelleting properties ..	Satisfactory
Shrinkage on Moulding ..	0·005-0·008 in/in
Properties of Moulding	
General	
Specific gravity	1·35-1·40
Weight per cubic inch ..	0·78-0·81 oz
Pyramid hardness	43-47
Water absorption	85 × 110 mg (0·30-0·40%)
Mechanical	
Impact strength	0·16-0·19 ft lb
Tensile strength	7,000-8,000 lb/sq in
Ultimate crushing strength	31,000-36,000 lb/sq in
Cross-breaking strength (ultimate fibre stress in bend)	10,000-11,000 lb/sq in
Young's modulus in bend ..	9·0-10·0 × 10^5 lb/sq in
Electrical	
Volume resistivity at 20° C 75% relative humidity ..	100-500 × 10^4 megohm-cm
Water-immersed ..	50-200 × 10^4 megohm-cm
Surface resistivity at 20° C Water-immersed ..	5-30 × 10^4 megohms
Dielectric strength at 20° C	220-300 volts/mil
at 90° C	100-150 volts/mil
Power factor at 20° C and 800 c.p.s.	0·03-0·04
S.I.C. (permittivity) at 20° C and 800 c.p.s.	5·8-6·5

TABLE II

Physical Properties of a Typical Urea Formaldehyde Moulding Powder, Paper-filled

Special Properties	Gives mouldings in translucent and opaque light-fast colours. Mouldings are odourless and tasteless and resistant to tracking by low-voltage low-frequency arcs.
Colours	Translucent and opaque colours.
Moulding Conditions	
Temperature	120-150° C (248-302° F)
Pressure	1-2 tons/sq in
Rate of Cure	
Minimum cure for 0·05 in. thickness at 145° C ..	25-30 seconds
Powder Properties	
Bulk density	0·7-0·8 gm/c.c.
Bulk factor	1·9-2·2
Shrinkage on Moulding ..	0·007-0·010 in/in
Properties of Moulding	
General	
Specific gravity	1·49-1·58
Weight per cubic inch ..	0·86-0·92 oz
Pyramid hardness	45-55
Water absorption	230-400 mg (0·8-1·4%)
Mechanical	
Impact strength	0·15-0·24 ft lb
Tensile strength	7,000-10,000 lb/sq in
Ultimate crushing strength	28,000-35,000 lb/sq in
Cross-breaking strength (ultimate fibre stress in bend)	11,800-13,500 lb/sq in
Young's modulus in bend ..	9·5-10·5 × 10^5 lb/sq in
Electrical	
Volume resistivity at 20° C 75% relative humidity ..	50-100 × 10^4 megohm-cm
Water-immersed ..	10-100 × 10^4 megohm-cm
Surface resistivity at 20° C 75% relative humidity ..	150-1,400 × 10^4 megohms
Water-immersed ..	100-1,000 × 10^4 megohms
Dielectric strength at 20° C	200-250 volts/mil
at 90° C	60-80 volts/mil
Power factor at 20° C and 800 c.p.s.	0·04-0·08
S.I.C. (permittivity) at 20° C and 800 c.p.s.	7·0-9·0

Final polymerisation takes place with the heat and pressure of the moulding cycle.

The final moulding product can be greatly influenced by the addition of varying fillers, and indeed the fillers that can be used influence the final choice of material for a given component. The effect of these fillers indicates the British Standard category to which the 'powder' belongs; they vary in type from wood flour to such materials as cotton linters, asbestos, nylon, mica, etc. Thus by choice of grade and filler a component can be produced which will have high shock resistance, high dielectric strength or heat resistance, etc.

This type of material has the one big disadvantage that the colour is confined to black, brown, walnut and some very drab shades, but in technical mouldings this range is usually quite sufficient. There is, however, another very important type of

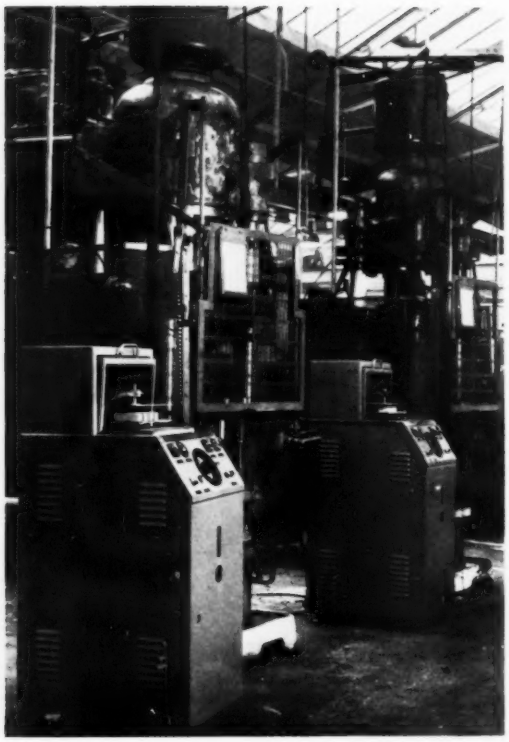


Fig. 1.—Two of the down-stroke hydraulic compression presses and 'English Electric' radio-frequency preheaters

thermo-setting material in urea formaldehyde, which gives a very great range of colours, translucent and opaque.

The production of ureas is basically the same as phenolics, but the proportion of formaldehyde is higher. In the production of bright colours, the use of fillers is restricted to wood flour and paper, and therefore the range of materials is not as wide as in phenolics.

Thermo-plastic Group

The characteristic properties of this group are that the materials may be re-softened by heat and re-set by cooling, theoretically an indefinite number of times. It is an exceptionally important group, comprising many complex attributes and giving a wide range of properties.

The most important members of the group are the cellulose plastics, vinyl compounds, styrenes, polythene, acrylics and the super polyamides.

Cellulose Plastics

Cellulose acetate is the principal moulding medium, and is produced by the action of acetic acid on cotton. The basic material is mixed with plasticizers, usually a camphor, solvents and pigments. The mix is worked up into a dough, which is rolled on warm rollers, causing solvent evaporation and the production of hides. For moulding purposes these sheets or hides are diced into granules.

The Vinyl Plastics

These are mainly represented by polivinyl chloride and polivinyl acetate (PVC and PVA). They contribute to a very wide range of materials. The manufacture of the final product is very similar to that of the cellulose products; initially

Fig. 2.—Loading the bottom cavity of a compression press with preformed thermo-setting material

Fig. 3.—Preformed powder being loaded into an R.F. preheater to advance the curing stage and reduce the time cycle

acetylene from calcium carbide is the base, and by condensation with the acid constituent it forms a monomer. Polymerisation produces long-chain solid polymers, suitable for moulding.

By varying the range of the polymer, or by making co-polymer products, a wide range of materials can be produced which extends from rubber-like types to hard rigid types. The range has a high chemical resistance. Polystyrene comes within this type of manufacture, being strictly speaking a vinyl type resin. Polystyrene, apart from the new high-impact type, is the most brittle thermo-plastic, but its electrical properties are outstanding. In heat resistance it surpasses the other thermo-plastics, although none has high resistance.

Polythene

Polythene is related to the synthetic rubbers and is a hydrocarbon. The actual manufacture is patented and very little is known about it. It has a wide range of application, being a tough and flexible solid polymer of high chemical inertness with high water and chemical resistance and very good dielectric properties.

Acrylic Plastic

The principal acrylic in use is methyl methacrylate known as Diakon or Perspex. This is a production of acrylic acid reacted with methyl alcohol giving methyl acrylate. By going further into chain reaction and adding a methyl, methyl methacrylate is produced. This has been an exceptionally popular plastic and has an extensive range of use.

Super Polyamides—Nylon

Nylon is perhaps the only plastic to approach the popularity of perspex. It is a very long chain super-polymer, formed by the reaction of adipic acid with hexamethylene diamine; the polymeris-

Fig. 4.—Polishing the top force of a mould, with bottom force in background

Fig. 5.—Toolroom light die sinker, working on mould cavity

ation of the resultant product is extruded and chipped for moulding. Nylon offers a very stable, hard wearing and self lubricating material.

Moulding of Plastic

The moulding of plastic falls into two main fields, compression and injection. The thermo-setting materials are compression moulded or, as a variation of this, transfer moulded, and thermo-plastics are injection moulded. The reasons will be understood from the following descriptions.

Compression Moulding

In the system of applying heat to the material whilst under pressure, a simple form of down-stroking hydraulic press is employed (Figs. 1 and 2) with an open mould fixed to the press and on to electrically heated platens. The mould comprises a top and bottom force, as illustrated in Fig. 4.

The heated mould is opened, the moulding material is placed in the bottom force cavity and the mould closed hydraulically. The material under heat and pressure becomes plastic and flows into the design of the cavity. This brings on the final reaction discussed earlier, giving a hard and infusible material in the shape desired.

Transfer moulding is a similar process, but the material is 'transferred' into the tool from a 'pot'. It is found sometimes that with intricate shapes or multi-insert moulds this system gives better and speedier flow.

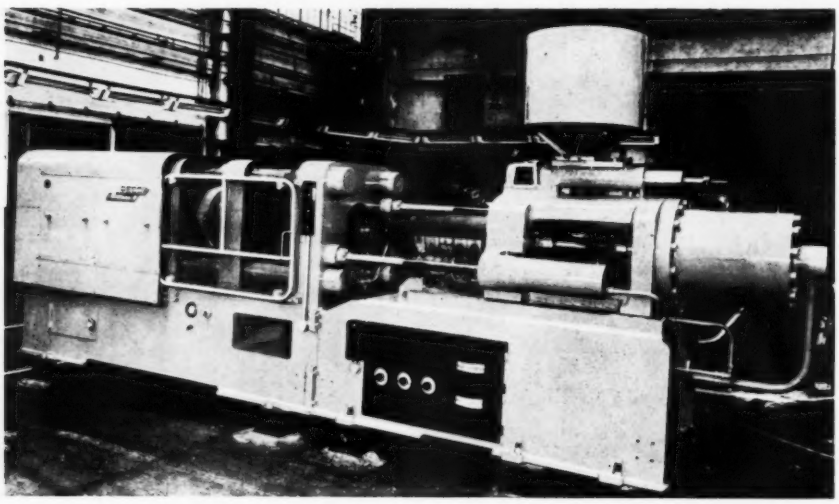


Fig. 6. 'Peco' 16/24 ounce injection moulding machine

Fig. 7. Moulded components for draw-out type relay

Fig. 9.—Traction relay covers

Injection Moulding

From the nature of thermo-plastic materials it will be appreciated that plasticised material, or heated material, to be set into a desired shape, has to be forced into a cold mould. A typical injection machine is shown in Fig. 6. Using this system, the moulding material is loaded into a hopper and allowed to pass into a heated cylinder fitted with a ram. On closing the mould the ram is allowed to move inwards and 'shoot' the heated material into the mould. As the setting is very quick on contact with the cold moulds, the rate of moulding can be very high.

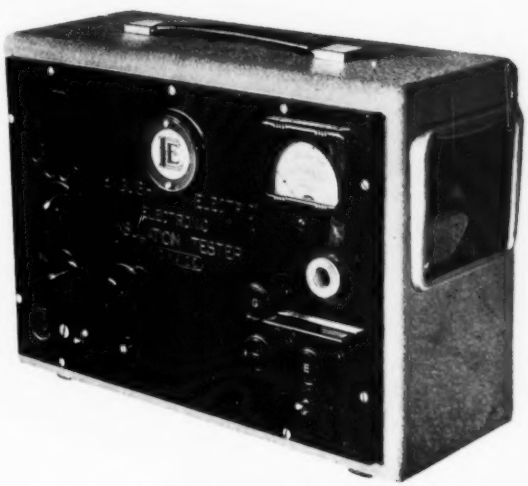


Fig. 8.—Moulded front panel for electronic insulation tester

Design

Some examples of components in plastics for 'English Electric' products are shown in Figs. 7 to 14.

There are many factors which influence the production of plastic mouldings, not the least being component and tool design. Whilst it is not possible here to go fully into the fundamentals of design, it is desirable to understand the principles involved. In many instances it is quite easy to simplify a component to facilitate and cheapen moulding. The main constituents are the 'top' and 'bottom' forces, but great variation is involved by the necessary introduction of undercuts, holes, inserts, etc., which may necessitate the use of multi-part forces or split tools.

Mould design is related directly to the component, and in prior designing a particular component the final production stage should be envisaged, or preferably the technical production staff should be consulted at the outset. There are several factors which may usefully be mentioned:—

1. Many components call for overtight tolerances;

Fig. 10.—*Control knobs for domestic appliances, in urea and polystyrene*

a tolerance guide is available in the 'English Electric' specification.

2. Large flat or long narrow components in thermosetting material may warp in later life. The provision of ribbing or a change in material may prevent this.
3. An ample dimension should be allowed between moulded holes to ensure physicai strength, and holes should be kept away from edges of mouldings, where insufficient wall thickness may cause cracking or breaking away.
4. To allow easy ejection from the mould, a good draft or taper should be allowed whenever possible.
5. The moulding-in of holes or inserts at an angle or at right angles to the direction of moulding should be avoided whenever possible, as it usually results in a loose insert or core, which increases the time taken for the moulding cycle.
6. Wall thickness should be uniform where possible, to allow consistent 'curing' of the moulding.
7. Corner radii should be provided and sharp edges avoided in general.
8. The depth of moulded holes of inserts should be related to the diameter. Long pins or insert carriers placed in the flow of the material can

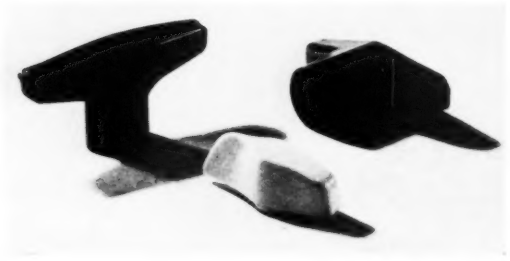


Fig. 11.—*Domestic appliance control knobs, in urea*

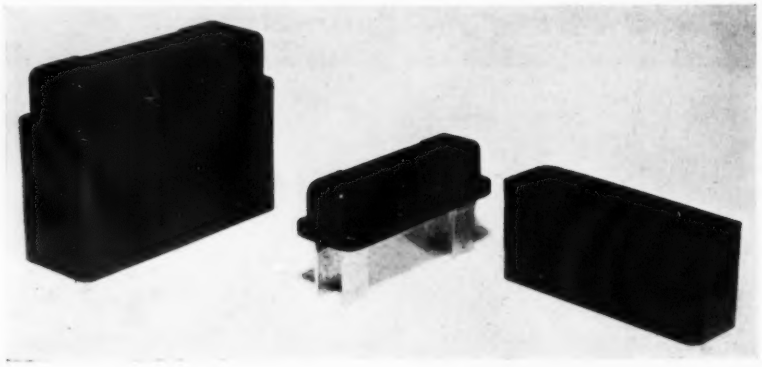


Fig. 12.—*Fuse bases and handles*

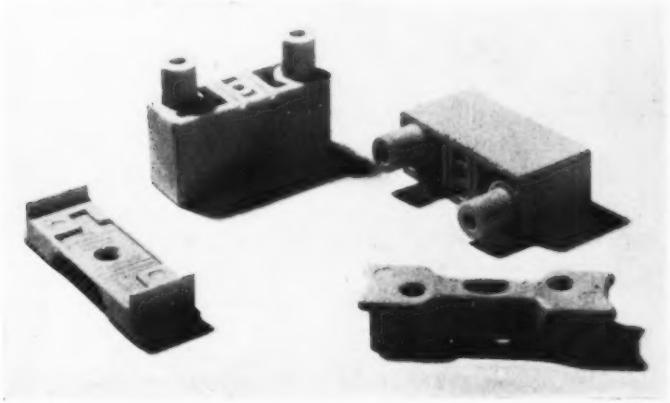


Fig. 13.—Fusegear components in coloured urea formaldehyde

bend or even shear under the pressure. Moulded threads are often quite adequate, but normal machine tolerances cannot be held.

It is not possible to lay down any fixed rules for design, or always to eliminate unseemly features, but by discussion bad points may often be improved, the design simplified and a cheaper but equally efficient component produced. It is within this sphere that the Plastics Department provides a comprehensive technical service, with its consultant group of engineers, designers, technologists and production control specialists. Designers entering the field of plastic components have often much to gain from the advice of the manufacturer before specifying a material or finalising a drawing. Within the range of available materials there is a solution to practically every problem, but the indiscriminate use of the same material for different products courts disaster.

Acknowledgments

The author is indebted to Imperial Chemical Industries Limited for the detailed information on the physical properties of moulding powders in Tables I and II, and to Peco Machinery Sales (Westminster) Limited for permission to reproduce the photograph in Fig. 6.

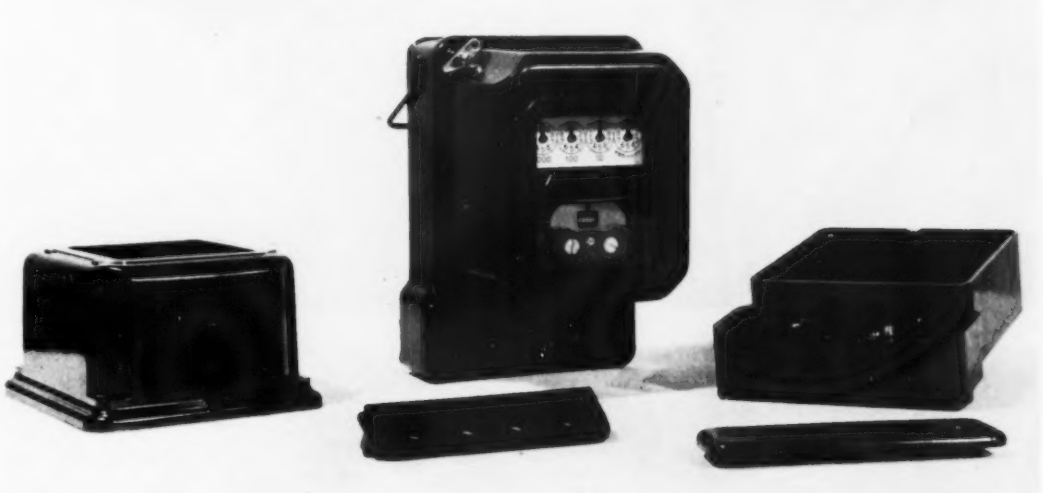


Fig. 14.—Moulded meter components

RECENT 'ENGLISH ELECTRIC' TECHNICAL PAPERS

BLANDFORD, A. R., M.I.E.E., Chief Electrical Engineer. *Post-war scene of some aspects of power engineering.* Address as Chairman of the South Midland Centre of the Institution of Electrical Engineers, at Birmingham on 4th October, 1954.

The theme of this paper is the rising consumption of electric power and the urgent need to economise our dwindling coal supplies. Electric power used in the mines is increasing but the coal thereby obtained provides a favourable balance, as in 1953 the power stations delivered 6% more electricity for an increase of only 3¼% in coal consumption. Despite the improved efficiency of coal mining and power generation, there is a great and urgent need for another source of heat in the form of atomic power.

The author discusses the increasing size and efficiency of generating units, and the attendant engineering problems; the question of power transmission, involving transformer and switchgear design and testing, and the possibility of high-voltage D.C. transmission; and concludes with a reference to railway electrification as an opportunity for fuel economy, and to 'application engineering' as an economical means of increasing industrial output.

YOUNG, J. B., B.Sc., A.M.I.E.E., Chief Engineer, Machine Design Department, and TOMPSETT, D.H., B.Sc.(Eng.), A.M.I.E.E., Assoc. Mem. A.I.E.E., Nelson Research Laboratories. *Short-circuit forces on turbo-alternator end-windings.* Institution of Electrical Engineers, Newcastle-on-Tyne, December, 1954.

A brief review is given of some factors relevant to short-circuit testing of alternators. The forces acting upon the stator conductors, particularly outside the slot, are described, and the difficulty of analytical assessment of the damage to insulation is indicated. Some details are given of the results of test short-circuits on a 60-MW turbo-alternator and also of tests on an experimental replica stator. The degree of correspondence between the short-circuit forces on an alternator and those on such a replica stator is considered in the light of tests carried out to establish this point. Various factors contributing to the severity of short-circuit forces which may occur in service and under present test conditions are discussed. The suggestion is advanced that a study of available data concerning actual operational faults be made with a view to obtaining agreement on a more realistic short-circuit test before machines are despatched.

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